AMERICAN SOCIETY
FOR
TESTING MATERIALS.

AFFILIATED WITH THE
INTERNATIONAL ASSOCIATION FOR TESTING MATERIALS.

PROCEEDINGS

OF THE

THIRTEENTH ANNUAL MEETING

Held at Atlantic City, New Jersey,
June 28-July 2, 1910.

VOLUME X.

W. O. Dunbar P.R.R. Test Dept Altoona Pa

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SUMMARY OF THE PROCEEDINGS OF THE THIRTEENTH ANNUAL MEETING.

ATLANTIC CITY, N. J., JUNE 28-JULY 2, 1910.

THE THIRTEENTH ANNUAL MEETING OF THE AMERICAN SOCIETY FOR TESTING MATERIALS was held at the Hotel Traymore, Atlantic City, N. J., on June 28-July 2, 1910. The total attendance at the meeting, including guests, was 347.

The following members were present or represented at the meeting:

Abraham, Herbert.
Adams, H. C.
Adams, J. K.
Aiken, W. A.
Ajax Metal Company, G. H. Clamer.
Akin, Thomas B.
Allen, Irving C.
American Asphaltum and Rubber Company, H. B. Pullar.
American Brass Company, William H. Bassett.
American Bridge Company, A. J. Christie.
American Foundrymen's Association, Richard Moldenke.
American Machinist, L. P. Alford.
American Steel and Wire Company, J. F. Tinsley.
Antisell, F. L.
Atwood, J. A.

Backert, A. O.
Barrett Manufacturing Company, William S. Babcock.
Bateman, T. J.
Baxter, Florus R.
Beale, H. A., Jr.
Berger Manufacturing Company, A. T. Enlow.
Berry, H. C.
Bethlehem Steel Company, The, E. O'C. Acker.
Bird, Robert Montgomery.
Blackmer and Post Pipe Company, L. G. Blackmer.
Bleininger, A. V.
Bonzano, A.
Bostwick, W. A.
Bowman, Austin Lord.
Boylston, H. M.
Boynton, C. W.
Buck, D. M.
Buffalo, Rochester and Pittsburg Railway, H. G. Burnham.
Burrows, Charles W.
Butler, George.

Campbell, Charles M.
Capp, J. A.
Carbon Steel Company, Harry W. Finnell.
Carnegie Steel Company, W. A. Bostwick.
Carney, F. D.
Carpenter, A. W.
Carpenter Steel Company, J. H. Parker.
Charls, G. H.
Chen, Wei Fan.
Christie, A. J.

Christie, James.
Church, Sumner R.
Churchill, Charles S.
Clements, Frank O.
Colby, Albert Ladd.
Colby, J. A.
Conradson, P. H.
Cook, H. E.
Corse, William M.
Corson, Charles E.
Cushman, Allerton S.

Davidson, G. M.
Davis, Eugene R.
Davis, William M.
Davis, William R.
Decker, Burton C.
DeKnight, Edward W.
Derby, W. A.
Dewar, John.
De Wyrall, Cyril.
Diller, H. E.
Dixon Crucible Company, Joseph, M. McNaughton.
Donohoe, John P.
Douty, D. E.
Dow, Allan W.
Drinker, Henry S.
Duerr, H. O.
Dunn, B. W.
Dunning, Hubert.

Easby, M. Ward.
Eisenschiml, Otto.
Electrical Testing Laboratories, F. M. Farmer.
Elmquist, F. A.
Engineering News, Frank C. Wight.
Engineering Record, John M. Goodell.

Farmer, F. M.
Ferguson, Lewis R.
Fireman, Peter.
Fisher, Henry W.
Force, Henry J.
Forrest, C. N.
Forstall, Alfred E.
Foster, H. W.
Fuller, Almon H.
Fulweiler, W. H.

Gaines, Richard H.
Gardner, Henry A.
General Electric Company, J. A. Capp.
Gibboney, James H.
Gill, Augustus H.
Goldbeck, Albert T.
Goodell, John M.
Greenman, Russell S.
Griffith, R. E.

Hall, John H.
Hancock, E. L.
Heckel, G. B.
Heidenreich, E. Lee.
Hemstreet, George P.
Hilles, Raymond W.
Hokanson, Martin.
Howard, James E.
Howard, J. W.
Howe, Henry M.
Hubbard, Prévost.
Huber, Frederick W.
Humphrey, Richard L.
Hunnings, S. V.
Hunt, Robert W.
Hunter, Joseph W.

Ickes, E. T.
Illinois Steel Company, W. C. Post.
Ingalls, F. P.
Iron Age, The, A. I. Findley,
Iron Trade Review, The, A. O. Backert.

Jeffers, John M.
Johnson, A. L.
Johnson, R. K.
Jones and Laughlin Steel Company, The, Jesse J. Shuman.

Kenney, L. H.

Kinkead, J. A.
Kinney, William M.
Koch, George B.
Kohr, Donald A.

Lackawanna Steel Company,
F. E. Abbott.
Lanza, Gaetano.
Lawson, T. R.
Lazell, E. W.
Lesley, Robert W.
Linder, Oscar.
Little, Arthur D., Inc.,
Hervey J. Skinner.
Loudenbeck, H. C.
Low, Frank S.
Lowe Brothers Company, The,
L. H. McFadden.
Lucas and Company, John,
F. A. Lane.
Lukens, Alan N.
Lum, D. W.
Lynch, F. D.
Lyon, Frank.

Macgregor, James S.
Macnichol, Charles.
MacPherran, R. S.
Mahon, R. W.
Mannhardt, Hans.
Marburg, Edgar.
Masury and Son, J. W.,
F. P. Ingalls.
Matchem, Charles A.
Mathews, John A.
McCleary, E. T.
McCready, Ernest B.
McDonnell, M. E.
McGrady, J. W.
McNaugher, D. W.
Meade, Richard K.
Meriwether, Coleman.
Metal Industry, The,
L. J. Krom.
Midvale Steel Company,
Radclyffe Furness.
Miller, Rudolph P
Mills, Charles M.
Missouri Pacific Railway,
W. J. Burton.
Moisseiff, Leon S.
Moldenke, Richard.
Moore, H. F.
Moyer, Albert.
Munsell, A. W.

National Cash Register Company,
The, F. O. Clements.
National Tube Company,
F. N. Speller.
Neal, C. S.
New Jersey Zinc Company,
G. C. Stone.
Norris, George L.

Olsen, Tinius,
T. Y. Olsen.

Page, L. W.
Page, W. Marshall.
Pennsylvania Steel Company, The,
J. V. W. Reynders.
Perry, R. S.
Pew, J. Howard.
Pickard, Glenn H.
Pittsburg Testing Laboratory,
John M. Bailey.
Polk, Anderson.
Porter, J. Madison.
Post, W. C.
Potts, Stephen C.
Powers, W. A.
Price, Charles P.
Provost, A. J., Jr.

Remington Arms Company,
N. A. Chase.
Reynders, J. V. W.
Richardson, Clifford.
Riehlé, Frederick A.,
William J. Tretch.
Roberts, J C.
Robinson, F. W.,
R. W. Lindsay.
Rock Products,
Fred. K. Irvine.

Rodman, H. B.
Roebling's Sons Company, J. A., H. J. Horn.
Rogers, Allen
Rys, C. F. W.

Sabin, A. H.
Sanborn, J. R.
Schenectady Varnish Company, W. H. Wright.
Sharpless, Philip P.
Sherrerd, John M.
Sherwin-Williams Company, The, Edward C. Holton.
Shore, Albert F.
Shuman, Jesse J.
Skinner, C. E.
Skinner, Hervey J.
Slocum, C. L.
Smith, Earl B.
Smith, Francis P.
Smith, H. E.
Sommer, Albert.
Souther, Henry.
Spackman Engineering Company, H. S., Henry S. Spackman.
Stafford, Samuel G.
Standard Steel Works, A. A. Stevenson.
Standard Underground Cable Company, The, H. W. Fisher.
Stevenson, A. A.
Stone, George C.
Stoughton, Bradley.
Studebaker Brothers' Manufacturing Company, J. A. White.

Talbot, A. N.
Tassin, Wirt.
Taylor, Knox.
Testing Laboratory, City of St. Louis, W. L. Hempelmann.
Mont Schuyler.
Thomas, 3d, George.
Thompson, G. W.
Tiemann, Hugh P.
Tilt, Edward B.
Tretch, William J.
Trist, N. B.

University of Pittsburg, J. Hammond Smith.

Van Gundy, C. P.
Voorhees, S. S.

Waldo, Leonard.
Walker, J. F.
Walker, Percy H.
Warner, George C.
Western Electric Company, Oscar Linder.
Westinghouse, Church, Kerr and Company, C. M. Chapman.
Westinghouse Electric and Manufacturing Company, C. E. Skinner.
Wetherill, C. T.
White, George D.
Wickhorst, M. H.
Wig, Rudolph J.
Wilson, Edward F.
Wilson, Percy H.
Winchester Repeating Arms Company, Rupert L. Penney.
Wood and Company, R. D., Walter Wood.
Wood, Walter.
Woodroffe, G. H.

Young, J. Bertram.

Total number, 256; attendance, not including firms, etc., whose representatives also hold membership in their own name, 237.

FIRST SESSION.—TUESDAY, JUNE 28, 3 P. M.

Vice-President Robert W. Lesley in the chair.

The minutes of the Twelfth Annual Meeting were approved as printed.

The annual report of the Executive Committee was accepted as printed. The Chair stated that the Regulations Governing Technical Committees, as given in Appendix II of the report, had been prepared by the Executive Committee after communicating with the chairmen of the various technical committees. The Chair also directed attention to the proposed modification of that paragraph in these regulations relating to the "Permanent Organization" of committees, referred to in the body of the report.

Mr. W. A. Bostwick moved that that paragraph be approved in the original form in which it appears in Appendix II. Mr. Walter Wood moved an amendment to this motion, that the question be referred to letter ballot of the Society. Mr. Edgar Marburg proposed the further amendment that the Executive Committee, in submitting this question to letter ballot of the Society, be instructed to have the notice to members accompanied by arguments pro and con prepared by the Executive Committee.

Mr. Bostwick accepted these proposed amendments with the understanding that the sense of the meeting on this question shall also be ascertained by vote and that the result of this vote shall be announced in connection with the notice for the letter ballot. The sense of the meeting was found to be favorable to Mr. Bostwick's original motion by an affirmative vote of 40 against a negative vote of 17. The original motion with the amendments above stated was then carried.

The amendments of the by-laws proposed by the Executive Committee and embodied in the annual report of that committee were then referred to letter ballot by a two-thirds vote of those present, as prescribed by the by-laws.

The Chair appointed Mr. Jesse J. Shuman and Mr. L. S. Moisseiff as tellers to canvass the ballot for officers and members of the Executive Committee.

The annual report of Committee A-3, on Standard Specifications for Cast Iron and Finished Castings, was presented by Mr. Walter Wood, Chairman.

In the absence of the authors the following papers were read by title:

"Tests of Cast-Iron Arbitration Test Bars." C. D. Mathews.

"Some Recent Tests of Cast Iron." A. E. Outerbridge, Jr.

"Unevenly Chilled and Untrue Car Wheels." T. D. West.

"The Forest Products Laboratory: Its Purpose and Work." McGarvey Cline.

On behalf of Committee E-1, on Standard Methods of Testing, Mr. Gaetano Lanza, Chairman, recommended that the proposed Standard Methods of Testing, presented by that committee at the last annual meeting and printed in Volume IX of the Proceedings, be submitted to letter ballot of the Society. This motion was carried by the requisite two-thirds vote.

Mr. J. A. Capp, Chairman of Committee B-1, on Standard Specifications for Hard-Drawn Copper Wire, presented a brief report of progress on behalf of that committee.

Mr. R. K. Johnson, as representative of Mr. H. V. Wille, Chairman of Committee A-10, on Standard Specifications for Staybolt Iron, recommended on behalf of that committee the adoption of the proposed Standard Specifications for Staybolt Iron, embodied in the report of the committee. That recommendation was approved by the prescribed two-thirds vote.

Mr. Henry Souther, Chairman of Committee A-7, on the Tempering and Testing of Steel Springs and Standard Specifications for Spring Steel, then presented an informal report on behalf of that committee.

The tellers reported that 225 ballots had been cast, and in accordance with their report the Chair declared the election of Mr. Henry M. Howe, President; Mr. Robert W. Lesley, Vice-President; Mr. Edgar Marburg, Secretary-Treasurer; and Mr. James Christie, member of the Executive Committee.

The meeting then adjourned till 8 P. M.

SECOND SESSION.—TUESDAY, JUNE 28, 8 P. M.

President Henry M. Howe, on assuming the chair, expressed his hearty appreciation of the honor conferred upon him through his election to the presidency, and pledged himself to do all in his power to meet the responsibilities of the office.

The following papers were presented and discussed:

"The Welding of Blowholes in Steel." Henry M. Howe.

"Copper-Clad Steel: Its Metallurgy, Properties and Uses." Wirt Tassin.

"Tests Steel and Wrought-Iron Beams." H. F. Moore.

"Strength of Steel from I-Beams." E. L. Hancock.

The meeting then adjourned till the following morning.

THIRD SESSION.—WEDNESDAY, JUNE 29, 10 A. M.

On Steel.

President Henry M. Howe in the chair.

The annual report of Committee A-1, on Standard Specifications for Steel, Mr. W. R. Webster, Chairman, was read by title.

The following papers were then presented and discussed:

"Low-Carbon Streaks in Open-Hearth Rails." Max H. Wickhorst.

"The Influence of Titanium on Segregation in Bessemer-Rail Steel." G. B. Waterhouse.

"Cupro-Nickel Steel." G. H. Clamer.

On invitation of the Chairman, Mr. Robert W. Hunt occupied the chair for the remainder of the session.

A paper on a "Test of a Structural Steel Plate Partly Fused by Short-Circuited Electric Current," was read by Mr. A. W. Carpenter.

In the absence of the authors the following papers were read by title:

"Elongation and Ductility Tests in Rail Sections under the Manufacturers' Standard Drop-Testing Machine." P. H. Dudley.

"Further Notes on the Annealing of Steel." William Campbell.

The annual report of Committee A-8, on Standard Specifications for Cold-Drawn Steel, was presented by the Chairman, Mr. C. E. Skinner, and discussed.

The meeting then adjourned till 8 P. M.

MEMORIAL SESSION.—WEDNESDAY, JUNE 29, 8 P. M.

President Henry M. Howe in the chair.

This session was held in honor of the memory of Dr. Charles B. Dudley, late President of the International Association for Testing Materials and of the American Society for Testing Materials. The proceedings of this session appear on pages 21 to 53 in this volume.

FIFTH SESSION.—THURSDAY, JUNE 30, 10 A. M.

On Cement and Concrete.

Vice-President Robert W. Lesley in the chair.

The following motion was introduced by Mr. Leonard Waldo and carried:

That a committee of three be appointed by the President to report at the next annual meeting of the Society on the proper use of the term "Modulus of Elasticity" (Young's Modulus) in engineering specifications and descriptions, including its use in describing non-ferrous metallic materials and their combinations.

Mr. R. L. Humphrey, Secretary of Committee C-1, on Standard Specifications for Cement, and Committee C-2, on Reinforced Concrete, presented progress reports on behalf of those committees.

The following papers were then read and discussed:

"Aluminates: Their Properties and Possibilities in Cement Manufacture." Henry S. Spackman.

"The Effect of Sodium Silicate Mixed with or Applied to Concrete." Albert Moyer.

"Comparative Tests of Lime Mortar, both in Tension and Compression: Hydrated Lime and Sand, Lump Lime and Sand, and Cement-Lime and Sand." E. W. Lazell.

In the absence of the author the paper on "Tests of Reinforced Concrete Columns Subjected to Repeated and Eccentric Loads," by Mr. Morton O. Withey, was read by title.

A paper on "The Distribution of Stress in Reinforced Concrete Beams, including a Comparative Study of Plain Concrete in Tension and Compression," was presented by Mr. A. T. Goldbeck.

A paper entitled "A Sand Specification and Its Specific Application" was then read by Mr. W. A. Aiken, and discussed.

An informal description of tests on modeled and concrete arches was then presented by Mr. W. R. Davis on behalf of himself and Mr. R. S. Greenman.

The meeting then adjourned till 3 P. M.

SIXTH SESSION.—THURSDAY, JUNE 30, 3 P. M.

On Preservative Coatings and Oils.

President Henry M. Howe in the chair.

The annual report of Committee D-1, on Preservative Coatings for Structural Materials, was introduced by the Chairman, Mr. S. S. Voorhees, and the reports of several sub-committees were then read, viz:

Sub-Committee B, on Inspection of Havre de Grace Bridge: W. A. Aiken, Chairman.

Sub-Committee C, on Inspection of Wooden Panels at Atlantic City: Robert Job, Chairman.

Sub-Committee E, on Linseed Oil: G. W. Thompson, Chairman.

Sub-Committee I, on Specifications for Varnish: G. B. Heckel, Chairman.

The annual report of Committee A-5, on the Corrosion of Iron and Steel, was presented by the Chairman, Mr. Allerton S. Cushman.

This was followed by a joint discussion of the reports of these two committees.

A paper on "Another Solubility Test on Protective Coatings" was read by Mr. G. W. Thompson.

In the absence of the author the paper entitled "Vermilion Paint for Railway Signals: Results of an Investigation," by Mr. Robert Job, was read by title.

The following papers were then read and discussed:

"The Painting of Cement and Concrete Structures." Charles Macnichol.

"Classification of Fine Particles According to Size." G. W. Thompson.

The annual report of Committee D-2, on Standard Tests for Lubricants, was presented by the Chairman, Mr. A. H. Gill.

The annual report of Committee D-3, on Standard Methods of Analysis of Fats and Oils, was presented by Mr. C. N. Forrest, Chairman.

A paper on "Some Exposure Tests of Structural-Steel Coatings" was then presented by Mr. C. M. Chapman.

The meeting then adjourned till the following morning.

SEVENTH SESSION.—FRIDAY, JULY 1, 10 A. M.

On Testing Machines and Apparatus.

President Henry M. Howe in the chair.

A paper on "The 600,000-lb. Hydraulic Testing Machine of the University of Wisconsin and Its Calibration," by Mr. H. F. Moore and Mr. M. O. Withey, was presented by Mr. Moore, and discussed.

A paper entitled "The Scleroscope," by Mr. A. F. Shore, was read by Mr. H. C. Berry. The reading of this paper was followed by a general discussion on "Tests of Metals for Hardness."

The following papers were then read:

"Some Testing-Laboratory Accessories." J. Madison Porter.

"Apparatus for Repeated Loads on Concrete Cylinders and a Typical Result." H. C. Berry.

"An Autographic Rubber-Testing Machine." T. Y. Olsen.

The following papers were read by title:

"Brinell Ball Test Applied to Wood." W. K. Hatt.

"The Structural Materials Testing Laboratories, United States Geological Survey: Progress during the Year Ending June 30, 1910." R. L. Humphrey.

A paper entitled "Apparatus for the Microscopical Examination of Metals," by Mr. Albert Sauveur, was read by Mr. H. M. Boylston.

The meeting then adjourned till 3 P. M.

EIGHTH SESSION.—FRIDAY, JULY 1, 3 P. M.

President Henry M. Howe in the chair.

The Chair announced that the form of the motion adopted at the Fifth Session relative to the appointment of a committee to define the term "Modulus of Elasticity" was not in conformity with the long-established usage of the Society, and that the Chair would accordingly entertain a motion for a reconsideration of that action. Such a motion for reconsideration having been made and passed, the original motion was carried in the following amended form:

That the Executive Committee be requested to consider the desirability of appointing a committee to report on the proper use of the term "Modulus of Elasticity" (Young's Modulus) in engineering specifications and descriptions, including its use in describing non-ferrous metallic materials and their combinations.

On invitation of the President, Mr. James Christie then assumed the chair.

A paper on "The Determination of Soluble Bitumen," by Mr. Prévost Hubbard and Mr. C. S. Reeve, was read by Mr. Hubbard and discussed.

The following papers were then presented by their authors and discussed:

"Improved Instruments for the Physical Testing of Bituminous Materials." Herbert Abraham.

"Necessary Reforms in Specifications for Petroleum Products." Albert Sommer.

"A New Machine for Testing Pitch." T. Y. Olsen.

The annual report of Committee D-8, on Waterproofing Materials, was presented by the Chairman, Mr. W. A. Aiken, and discussed.

A paper on "Fuel Investigations, United States Geological Survey: Progress During the Year Ending June 30, 1910," by Mr. J. A. Holmes, was read by title.

The meeting then adjourned till the following morning.

NINTH SESSION.—SATURDAY, JULY 2, 10 A. M.

Mr. L. W. Page in the chair.

After calling the meeting to order, the Chair invited Mr. J. M.

Goodell to the chair and then presented the following annual reports on behalf of the committees under his chairmanship:

Committee C-3, on Standard Specifications for Paving and Building Brick.

Committee D-4, on Standard Tests for Road Materials.

The latter report contained the recommendation that the "Proposed Tests for Bituminous Compounds for Roads and Pavements, including Method of Sizing and Separating the Aggregate in Asphalt Paving Mixtures" be passed to letter ballot of the Society. Inasmuch as the report in question had not previously been submitted to letter ballot of the Committee, the Secretary was instructed by two-thirds vote to refer the above recommendation to letter ballot of the Society, provided the previous vote of the Committee by letter ballot should be unanimous.

The annual report of Committee C-4, on Standard Specifications and Tests for Clay and Cement Sewer Pipe, Mr. Rudolph Hering, Chairman, was presented by Mr. A. J. Provost, Jr., Vice-Chairman.

The annual report of Committee D-7, on Standard Specifications for the Grading of Structural Timber, was, in the absence of the Chairman, Mr. Hermann von Schrenk, presented by the Secretary. The recommendation of the Committee, that the proposed Standard Specifications for Yellow-Pine Bridge and Trestle Timbers, presented last year and printed in the Proceedings, should be referred to letter ballot of the Society for adoption, was approved by the requisite two-thirds vote.

A brief verbal report on behalf of Committee A-6, on the Magnetic Testing of Iron and Steel, was presented by Mr. J. A. Capp.

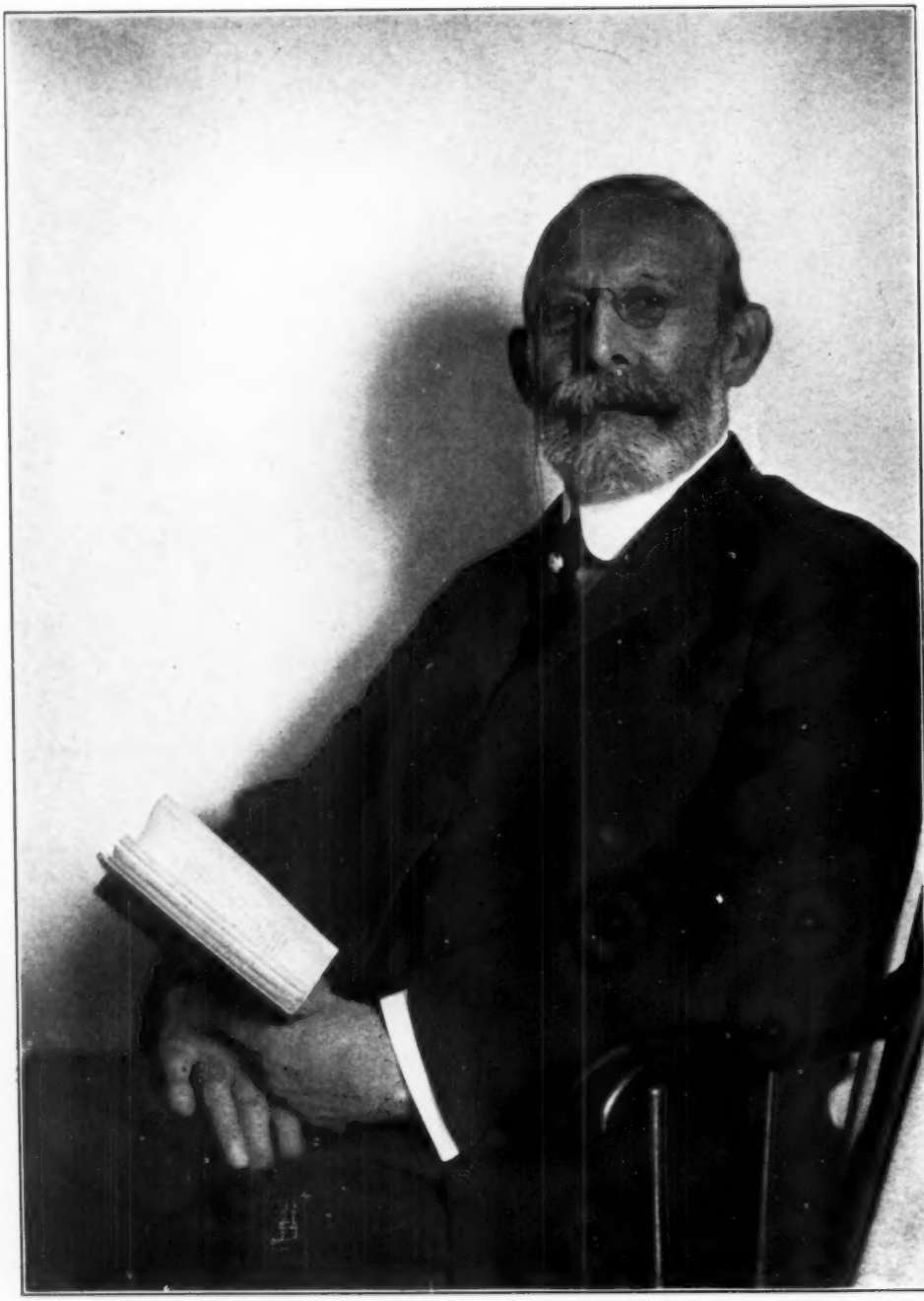
A paper on "A Comparison of Magnetic Permeameters" was presented by Mr. Charles W. Burrows.

In the absence of the authors the following papers were read by title:

"The Exponential Law of Endurance Tests." O. H. Basquin.

"Measured Strains in a Steam Boiler under Hydrostatic Tests." James E. Howard.

The Chairman then declared the meeting adjourned *sine die.*



Chas. B. Dudley

Memorial Session

held in honor of the memory of

Charles B. Dudley

LATE PRESIDENT OF THE INTERNATIONAL ASSOCIATION FOR TESTING MATERIALS AND OF THE AMERICAN SOCIETY FOR TESTING MATERIALS

At Atlantic City, N. J.

on the Evening of Wednesday, June 29, 1910.

Program of Exercises

THE LIFE AND LIFE-WORK OF CHARLES B. DUDLEY, 1842–1909

President Henry M. Howe presiding, the Vice-President of the Society, Mr. Robert W. Lesley, offered some introductory remarks on behalf of the Executive Committee. The life and life-work of Dr. Dudley in its different phases was then presented by the following speakers:

As a Railroad Man..... Theodore N. Ely
As a Chemist..... Edgar F. Smith
As a Metallurgist..... Henry M. Howe
As a Mentor..... B. W. Dunn
As a Citizen..... W. H. Schwartz
A Personal Tribute..... Robert W. Hunt

The following minute, prepared by Dr. Henry M. Howe, was then adopted by a rising vote:

"Let us record at once our deep grief and our deeper gratitude, our grief indeed at the loss of a great leader and dear friend, but above all, our gratitude that we have had the privilege of being led.

Such measure of usefulness as our Society has had it owes in very large part to that leadership. Here was a most rare combination of qualities, the sterling, the intellectual, the human, the judicial, each on a high level, all combining to form a character, a personality, whose like we shall not look upon again.

With a clear head to see the world's needs, to part the essential from the accidental and the merely concomitant, went the skillful and persuasive tongue to make clear to the rest of us what he had first made so clear to himself. With these went the perfect fearlessness, apparently even the unconsciousness of either danger or fear, which made him lead on where others would have flinched. With these again went his calm, clear, good judgment, which seemed to tell him spontaneously which among the good things that needed doing were the most worthy of being done, and what were the best and surest ways of doing them.

With all these admirable qualities went that which was necessary to the accomplishment of his high purposes, his kindness of heart, his sympathy and his tact, which made us all his allies in what he undertook. Had he a proposal? Our affection and veneration for him made us almost its advocates before it was unfolded. Its intrinsic wisdom, and the clearness with which he expressed it, found an audience ready, almost anxious, and certainly expecting to be convinced.

Great as were his tangible works, his greatest was the imponderable. Standing on a high platform, his call raised us towards his level, all the more effectively because of his complete unconsciousness of his own height. We who have known and loved him are for that knowledge and that love the better and the higher—how much, ah, who shall say?"

ADDRESSES DELIVERED AT THE MEMORIAL SESSION IN HONOR OF THE MEMORY OF CHARLES B. DUDLEY.

Introductory Remarks by the Vice-President,

Mr. Robert W. Lesley.

In the printed report before you to-day, there is a minute prepared by Dr. Howe, our honored President, and adopted by the Executive Committee as a memorial to Dr. Dudley. It is so expressive and so full of beautiful thought and feeling that it leaves but little to add. However, as your Vice-President, and one who has been associated with Dr. Dudley from the earliest days of our Society, I cannot let the occasion pass without adding my mite to the monument of love and affection we will erect to-day to the memory of one of the greatest men this country has ever known. He was a *man*—a versatile and many-sided man. When we think that he is to be described by those who knew him best as he appeared in the various branches of science, in his capacity as a railroad man, as a chemist, as a metallurgist, as a mentor, and as a citizen, how can we fail to realize that this was a man of giant intellect and sterling character? But say of him what we will, in every relation of business and scientific life he was, above all, the man—kindly, true, affectionate and loving. He was a diplomat of the heart, a nobleman of Nature's handiwork, a man of the broadest outlook and widest perspective. No Marius he, immersed in the mire of petty and narrow things, but a soldier of light, with his head on high, seeing all sides of every question and deciding rightly and clearly from his elevated point of view, his worldly experience, his Christian impulses, and his rare judgment.

In our Society his manly, melodious voice, his irresistible smile and musical laugh carried everything before them. Who could resist them, combined as they were in the delightful personality of Dr. Dudley? No difficulty ever arose that his presence could not compose, no trouble that his instinctive tact could not brush away. A member of the International Association for Testing

Materials in 1896, one of the members of the American Section of the International Association for Testing Materials at the time of its organization in 1898, and President of the American Society for Testing Materials at the time of its formation in March, 1902, Dr. Dudley's career with us was synonymous and synchronal with the development of the Society.

In his connection with our organization Dr. Dudley stood at all times for the best and the highest. To him, as the exemplar of the art of testing, and as the pioneer in that most important field, we owe largely the growth of our Society. In honoring him by making him our President we honored ourselves by putting at the head of our organization a man who stood in the forefront of the art for which our Society stands, and as we look back at the various meetings of the Executive Committee at which Dr. Dudley presided, we see a great work well planned and well executed. When we think of occasions where petty strife and small jealousies or rivalries arose, we remember how, with the mind of the philosopher and the genius, he was able to quell all difficulties and bring order out of disorder. When we think of him presiding at the meetings of our Society, we recall how we were impressed with his knowledge of every subject presented. Whether the question related to metallurgy, chemistry, railroading, or the manufacture of paint, glass, cement, or iron and steel, Dr. Dudley was always ready with an apt question, a well-applied story or a practical illustration. Such knowledge as this on the part of the presiding officer was an inspiration to the speaker, who always felt that he had our President's sympathy and intellectual appreciation of his efforts. It was this wonderfully keen knowledge and incisive speech—always the right word at the right time—that made our meetings so interesting to all, both young and old. Dr. Dudley's love of youth, his passion for developing and uplifting minds, and his encouragement to budding genius—the prize crop of our Society—were the kindly lights that always led the younger men forward in the work of our organization, making them feel at all times that they had a warm and appreciative friend in the chair, while to us older men he was the incarnation of sympathy, fairness and sound judgment.

Again do we look at Dr. Dudley as a President-host, a man who, no matter how high his place in our Society, had always a

kindly smile and a friendly hand to greet every member at the meetings of our organization. His passage through the halls of the hotel or along its porches, marked by kindly smiles and friendly greetings, is familiar to us all; but above all, Dr. Dudley as the presiding officer at our annual dinners stood in a place particularly his own. Let us look back at one dinner which stands pre-eminent in the hearts of all of us, the dinner given to Dr. Dudley when he and Mrs. Dudley returned from their European trip. How full of life, of boyhood spirits, he was, how proud of his wife and of her enjoyment of our appreciation of him. How keen his sense of appreciation and enjoyment of the occasion, and of the assembly about him which had gathered to do him honor and to welcome him home. Every one of us was made to feel that Dr. Dudley was our individual host, was brought almost to believe that the whole thing was in honor of each individual member and not of Dr. Dudley. At this particular dinner his appreciation of the speeches and his genial face lighting with affection for his associates and friends, we cherish as among the most blessed memories of our late President.

How truthfully does his career illustrate these words of Bryant:

> "So live, that when thy summons comes to join
> The innumerable caravan, that moves
> To that mysterious realm, where each shall take
> His chamber in the silent halls of death,
> Thou go not, like the quarry-slave at night,
> Scourged to his dungeon, but, sustained and soothed
> By an unfaltering trust, approach thy grave
> Like one who wraps the drapery of his couch
> About him, and lies down to pleasant dreams."

CHARLES B. DUDLEY AS A RAILROAD MAN.

By Theodore N. Ely.

Fellow Members and Guests:

We have come together this evening as a sympathetic company of admirers to commemorate the distinction of our friend and fellow member, Charles Benjamin Dudley, about whose life as related to his railroad work, I have been asked to speak. I have known it from the beginning, but I can give you no just or adequate idea of its extent and importance in the limited time at my disposal.

When one through character and ability has greatly advanced his profession, it is fitting that we who knew him should join in recording our appreciation of him, and in this particular case it is our wish that Dr. Dudley through all time may be remembered as one who was foremost in proving the value of chemical research as applied to the wants and needs of a great transportation company, and the importance of bringing it into closer relations with the manufacturers and merchants of the country.

Dr. Dudley spent his entire railroad life in the service of the Pennsylvania Railroad Company, for it was in November, 1875, that he began the work that was to continue without interruption for thirty-five years; and inasmuch as at that time there was no department of railroad chemistry in this country, nor, I think, elsewhere, Dr. Dudley may be said to have been the first head of a chemical laboratory devoted exclusively to railroad work.

It will interest you to know that it was upon the recommendation of his friend, the eminent scientist, Dr. Coleman Sellers, that Dr. Dudley was employed by the Pennsylvania Railroad, and I wish to record the words of Dr. Sellers, who said, "I know just the man to organize and carry on a department of the kind you have in mind." Thus early in his career, Dr. Dudley's abilities were recognized.

Now, what was that department, and what character of man did it need?

As to the department: At the time of which we speak the Pennsylvania Railroad had some little apparatus for carrying out physical tests, but it had made no provision for conducting chemical examinations. Analyses had been made occasionally by outside chemists, but the work had not reached the dignity of systematic investigation. An engineering laboratory in its broadest sense having been authorized, a department of physical tests and one of chemical tests were decided upon, which, although separate in their specialities, should work in collaboration. The first was organized with the staff and appliances already at hand as a nucleus; the new department of chemistry was organized with Dr. Dudley at its head.

Now, as to the character of the man who could be safely entrusted with this responsibility: It was necessary that he should be honest, above reproach, loyal to the company he served, perfectly fair-minded, patient, enthusiastic, with strong initiative, and with health and strength for great exertions; it was necessary that he should have the faculty of working in harmony and in the right spirit of cooperation with other departments; that he should be possessed of ability in the selection and training of his assistants, and that he should be pre-eminently a student, with a facility for clear expression.

Dr. Dudley came to the service with many of these powers already proven. As a volunteer soldier during the Civil War, with honorable wounds received in action, he had given proof of his loyalty and bravery. At Yale University, where he went at the close of the war, the record he made for hard and faithful study, under financial conditions that would have discouraged most young men, won for him academic and scientific distinction, and testified to the fact that he was worthy to be entrusted with important duties.

And I will say in passing that Dr. Dudley did not make his decision to enter the railroad lightly; it was a struggle for him to relinquish the strong desire he had to make the study of physiological chemistry his specialty. But the extent and importance of the new field of endeavor, and the fact that his service would be with a railroad managed from its beginning by professional men, sympathetic with his efforts, determined his decision, and he entered upon his new work with his characteristic enthusiasm.

It should be kept in mind that the undertaking was largely an experiment, the permanency of which depended both upon the energy and ability of the man who conducted it, and upon his success in making himself a necessary part of an organization already complete in most respects. That the duties of this post had to be cooperative to a large extent, would for many men have constituted an insuperable objection; but not for Dr. Dudley.

I have dwelt at considerable length upon the circumstances connected with the employment of Dr. Dudley by the railroad company, because it should not be overlooked that thirty-five years ago the attitude of the public mind was one comparatively antagonistic and sceptical regarding the work of scientific men as applied to the practical affairs of life, and for that reason the Company was fortunate in the selection of a man like Dr. Dudley, whose strong personality turned these narrow prejudices into a broad spirit of mutual helpfulness.

I doubt whether those of you who are not familiar with the needs of a railroad company appreciate the variety and magnitude of its physical requirements, and realize that almost every conceivable article of commerce and manufacture is required for its construction and operation. An endless number of questions and problems find their way to the laboratory for solution. A knowledge of physics and chemistry is constantly brought into requisition, and must be supplemented by good sense and clear thinking to meet the difficulties constantly arising, and to aid in devising new and improved methods for the greater safety and economy of operation. That the interests of the railroad may be protected, the examination of the enormous quantity of supplies purchased and consumed by it, both as to quality and fitness, is in itself a great work.

Very early in his service Dr. Dudley found that in the purchase of supplies, the certainty of obtaining uniform or suitable quality could be insured only by describing to the seller in plain language exactly what was wanted; that, again, if the sources of supply were to be multiplied, it was necessary that the Company's wants should be so stated that every seller would know he was making his offer upon exactly the same basis as his competitors; that it was necessary, also, for merchants and manufacturers to have implicit confidence in the honesty of those who inspected the purchased materials.

Dr. Dudley was upheld in his ideas, and began at once the long, painstaking and arduous development of what is now known as the "standard specification." The details of this development would be a story in itself, but I shall cut them short by saying that to Dr. Dudley more than to any other man belongs the credit of establishing the principle of purchase by specification, which is now the universal practice in this country. I verily believe that had he not been able to win the confidence of manufacturers in his sincerity and in his knowledge of his subjects, he would have failed entirely.

I am greatly embarrassed in trying to select for mention any of the many investigations that were made and the specifications that were prepared during Dr. Dudley's administration of the laboratory, for even a reference to each would unduly detain you.

The work of the chemical laboratory was begun at Altoona in a modest way, a fact which gave Dr. Dudley an opportunity to become acquainted with those with whom he was to be associated, and to familiarize himself with his surroundings, and I might add, very properly, to accustom himself to the formal character of a railroad organization. The laboratory staff consisted of himself and one or two untrained helpers, and from this beginning grew the present force of thirty-four chemists and other assistants.

During the first few months a number of relatively minor investigations were carried on. The first of these, if I remember rightly, was the study of the tallows used for locomotive cylinder lubrication. The great loss due to the rapid corrosion of the valves and other parts of locomotives had become very serious. Dr. Dudley found that by careful and proper rendering and the selection of fresh tallow the difficulty could be alleviated, and a specification was drawn that gave the promised relief. In later years the introduction of sight-feed lubricators has made the use of cylinder oil possible, but Dr. Dudley's investigation of tallows should not be forgotten, nor its importance overlooked.

It seems hardly necessary to speak to you of Dr. Dudley's great work in connection with the steel-rail problem, but it was a subject that he had very much at heart. Early in 1877 his investigations were started. Before entering upon them, however, his ever-present desire for thoroughness led him to ask permis-

sion to spend several weeks at the Sheffield Scientific School, under Dr. Allen, the better to perfect himself in steel analyses. His first paper on the properties of steel rails, read before the American Institute of Mining Engineers in 1878, was destined to attract world-wide attention. It was a very thoughtful and suggestive treatment of this most difficult subject, and was discussed with great vigor by engineers and chemists. This paper and the others that followed it have been published in several languages, and I would commend it to those of you who are engaged in research work, as a pattern of orderly arrangement and of clear deduction. Dr. Dudley's work upon this subject continued to the end. He was Chairman of the Research Committee of the Pennsylvania Railroad System's Rail Committee.

But this was only the beginning of Dr. Dudley's study of steel products. This material was being freely offered as a substitute for iron, and as one may easily imagine, the laboratory was obliged to give constant attention to the subject, for it was not easy to determine to what extent steel could be adapted advantageously to the many uses of the railroad.

One of the most far-reaching and important investigations made by Dr. Dudley was in connection with the purchase and use of burning oils. The vital question of safety in railroad operation was involved. Signal lights were apt to grow dim or to fail entirely, and a general feeling of disquietude prevailed among those responsible for the movement of trains. Dr. Dudley found that signal oils made from lard oil at the Company's own oil house gave no trouble whatever. The great difficulty was to discover why purchased lard oil should give different results. Methods for the examination of oils had not been fully developed, and those with special information were usually manufacturers who were not quick to disclose it. But, almost accidently, Dr. Dudley discovered in the course of his experiments that a reaction took place when acid was added to a mixture of cotton-seed oil and lard oil, and that the heat evolved was in almost exact proportion to the cotton-seed oil. The secret was out! Low-priced cotton-seed oil was being mixed with high-priced lard oil and sold for pure lard oil, so that the Company not only suffered in having unreliable signal lights, but in pecuniary loss as well. Of course, manufacturers were indignant and demanded proof.

But the method of examination was not disclosed, lest it might be circumvented. The railroad company had absolute faith in Dr. Dudley's tests and determined to accept for purchase no lard oil that did not meet them. As a result it was soon possible to buy freely a pure product. There was probably no time in Dr. Dudley's official career when he was brought face to face with a more difficult situation, and I mention it now because it was a case involving not science alone but high moral courage as well.

As in the case of steel, the uses of oils for manifold other purposes received Dr. Dudley's attention. He devised a thin wick burner which could be used without a chimney for burning kerosene oil. He made a long and careful study of journal lubrication, and in connection therewith his exhaustive study of bearing metals has borne fruit a thousandfold.

I cannot let this opportunity pass without saying a word about Dr. Dudley's equally exhaustive investigations of paints and varnishes. The manufacturers were stimulated and encouraged to improve their product and methods by useful suggestions made to them by Dr. Dudley during the course of his inquiries, and the public at large has benefited greatly thereby.

I must pass rapidly over such important items as the analyses of coals and water, and the preparation of a formula for disinfectants, the manufacture of which was carried out under Dr. Dudley's personal supervision. The latter led naturally to a study of the sanitary conditions of passenger cars and their disinfection. The specifications for plushes required a long study of dyes and textures. Of course electrical matters found their way to the laboratory and specifications were issued for them. The lighting of passenger cars by the carburetor system was worked out under Dr. Dudley's direction, and, notwithstanding many prophecies to the contrary, it became a safe and useful means of lighting.

I must not fail to speak of the series of articles describing the methods used in the Pennsylvania Railroad laboratory for testing material, which were written by Dr. Dudley in collaboration with Mr. P. N. Pease, and published in the *American Engineer and Railroad Journal*, for the information of manufacturers and others interested. These articles began in 1889 and were con-

tinued through several years, and did much towards bringing about the standardization of chemical tests.

I will close this very meager reference to the activities and accomplishments of Dr. Dudley's life with the railroad, with mention of a subject that deeply engrossed his attention at the time of his death. Dr. Dudley had for many years studied the perplexing question of the transportation of high explosives by the Pennsylvania Railroad, but soon saw that it was a problem that must be treated by the concerted action of the railways, and a little later, that it must come under Government supervision. Dr. Dudley individually did a prodigous amount of work in the development of a plan, which involved very delicate business and political judgment, as well as a thorough knowledge of the subject. The result was an agreement among the railways, and the adoption by the National Government of laws for the regulation of this traffic, and the assignment of an eminent United States army officer to assist in further perfecting the safeguards for the transportation of this very dangerous class of material.

And now, speaking for my official associates and for myself, I desire to pay this earnest and heartfelt tribute to Dr. Dudley's memory:

His service was of great and permanent value to the Pennsylvania Railroad Company. His activities extended beyond the bounds of the laboratory to the more general operations of the road in such full measure that in his death the Company will keenly feel the loss of his good counsel.

He has left behind him a noble heritage of honesty, fidelity, manliness and work well done. He won the friendship of every one in the service with whom he came in contact, from the highest official down and through the ranks to the man occupying the humblest position. He was a kind and generous friend to the young men and very solicitous for their advancement. A deep sense of personal grief pervades the service, and we shall ever mourn the loss of a valued friend and colleague, and an agreeable and stimulating companion.

CHARLES B. DUDLEY AS A CHEMIST.

By Edgar F. Smith.

Would that I were competent to speak adequately of Charles B. Dudley as a chemist! At the time your honorable Secretary assigned me this duty, I must confess, I thought I could discharge the responsibility, for in a general way I felt myself familiar with the career of our departed friend. When, however, I began actually and seriously to study the life work of your late President, I promptly recognized my insufficiency, and realized that I could only be a pupil—a pupil, however, in perfect sympathy and accord with the thought and purpose of the master.

I recalled how, in the very earliest days of his connection with the Pennsylvania Railroad, Dr. Dudley meeting me in the University of Pennsylvania, where, at that time, he frequently visited, would often in his cheery, enthusiastic way propound question after question relative to methods of determination or analysis, or would suggest a wholly new course of procedure in the estimation of a compound or element which was then engaging his thought. To my mind, our friend was a true pioneer in his chosen field of research, as well as a shining, brilliant exponent of the idea of making his special science do service to his fellow men. That he was a pioneer is recognized in statements of his own made in 1875. Listen: "So little was the possible use of a chemist appreciated and so little work was known that he could do on a railroad, that permission to have a chemist was granted more as a concession and as an experiment than with any faith or belief that the scheme would prove to be permanent or valuable." Indeed, he wrote, "It is also fair to say that at that time the field for work was as much unknown to the chemist himself as to the railroad officers." Then, as a true pioneer and an inspired researcher he set about informing himself as to the problems which were before railroads and to discover in what ways chemistry might contribute to the solution of these same problems. The steps pursued were taken only after earnest thought and much tedious, trying experi-

mentation; but as one follows this master mind in its workings, the mysteries are rapidly cleared away, and the unfolding and opening up read like fairy tales. I fancy much of the vivacity and enthusiasm of our friend came from the consciousness that in his struggle with obscure and knotty questions he was surely letting in the light, gradually at first, but in the end with such brilliant illumination "that he who runs might read." He was winning out! And to him came "the joy and exultation of soul which comes from the discovery of a natural truth and the realization that the most happy and heart-filling thing in the world is to come face to face with something which no one but God ever saw before."

As a pioneer in his particular field of investigation he did not discover new bodies to which were assigned sesquipedalian names, nor did he promulgate fanciful, unstable theories. For these he seemed not to have any great fondness. He patiently tested out methods of analysis, improved or perfected them, discovered new methods, and applied old and new alike to the solution of the thousands of problems which came to him as he advanced further and further in his studies. He was a keen, exact and most intelligent analyst. In his own domain he was, indeed, the master.

To the student of the life work of Charles B. Dudley, there looms up bright and clear, upon every side, the earnest endeavor to make his science serve mankind. Witness his unceasing efforts to ascertain the proper nature of all materials in use by railroads, his efforts to eliminate every contaminating substance that would be harmful to the wholesomeness of the real substance, his care to exclude all that might, in any way, endanger the lives of those who traveled by rail, his prolonged study to contribute to their comfort and health, as well as his steady aim to associate with himself others who might aid in spreading and expanding the new issues, bringing them into use wherever possible in the daily walks of life.

His deep, hearty interest in this Society is additional evidence of his ambition to make science and his contributions to it help you and me. His presidency of the International Association further demonstrates his purpose to have his philanthropy, for such his labors truly were, world-wide in its benefits.

When once the history of chemical science in America is written, there will be no brighter or more attractive page than that devoted to the story of the labors and achievements of Charles

B. Dudley, pioneer and benefactor, of whom it may be truthfully said:

"So might I, toiling morn till eve,
Some purpose in my life fulfill,
And ere I pass some work achieve,
To live and move when I am still.

"I ask not with this work combined
My name shall down the ages move,
But that my toil some end may find
That man may bless and God approve."

CHARLES B. DUDLEY AS A METALLURGIST.

By Henry M. Howe.

He who is privileged to speak to you of Dudley the metallurgist must needs trench on the ground of the eloquent friend who is entitled to speak of Dudley the citizen, and on the ground well assigned to our fellow of the silver tongue who is to pay a personal tribute to our great leader. For Dudley was first and foremost a man, yes, a man and a prophet, and only secondarily a chemist and a metallurgist; and as a metallurgist he simply brought to bear on metallurgy those qualities which made him revered, loved, and followed as a man.

As the metallurgist of the Pennsylvania Railroad Company he had a broad field for the exercise of his powers, in studying the varied and important uses to which that vast organization puts the metals and their alloys, in adapting the material to its service and the service to the necessary limitations of the material. Among the objects and materials which he helped greatly to improve are cast-iron car wheels; cutting tools of cast iron; springs; axles; boilers; fireboxes; stay-bolts; rails; and bearing metals. Among these there are several as to any one of which taken singly his work entitles him to high rank as an adaptive metallurgist. Beyond this his studies of copper, lead, zinc, phosphor bronze, phosphor copper, and tin plate, were of great value, in leading to the improvement of specifications, and in other ways. His achievements in this one field form a life's work of uncommon value, apart from his fruitful labors as a chemist, as a leader in the science and art of testing materials, and as a citizen.

But great as were the variety, labor, and ingenuity of his own direct experiments on these subjects, the wisdom, the sagacity, and the breadth of view with which he interpreted and applied his own results and those of others, were of even greater value to his employers and through them to the community, the employer of his employers.

The number of excellent qualities with which every fellow metallurgist must credit him is at first almost bewildering. He

was kind and more than kind; industrious, yes, indefatigable; keen; analytical; well informed; eminently fair and reasonable; receptive; clear as crystal in conception; lucid, graphic, and convincing in statement; absolutely faithful to his employers, yet just, honest, and even open to the opposing interests, to those with whom his employers bargained; original; independent; brave to the point of seeming unconscious of danger; stating his theses clearly and without shadow of equivocation, even when he stood alone and without an ally; yet so frank in acknowledging the limitations of his knowledge and the defects in his premises, that a change in his opinion because of new light rather brightened than dimmed his prestige. Withal he was so considerate of his opponents that his victories brought them no sting. With the fairness, gentleness, and chivalry of an Arthur went the strength and fearlessness of a Lancelot.

Is it possible to look on this list of admirable qualities, seeking vainly for offsetting defects, and yet to hold that these were separate and independent gifts? May we not more reasonably regard them as simply the various manifestations of a single great underlying principle, unselfishness or altruism? Was it not the direction of his vision, looking up, not down; out, not in; forward, not backward? For our own guidance I ask you now to consider this question earnestly with me.

To each of us the universe consists of two parts, first himself, second, all the rest. We naturally think of ourselves first, yes perhaps first, second, and even third, and only later and incidentally of the rest of the universe. But the prophet has the opposite point of view. In facing the problems which press on him every hour he has in mind rather the rest of the universe than his own personal interests. Whether he speaks with the trumpet of Moses, Elijah, or Confucius, in notes which echo distinguishably through all time to untold billions, or as Dudley spoke to the men of his day and guild, it is in the same key, based on the diapason of the Almighty.

If I am right in holding that it is not the sonority but the key, not the quantity, but the quality of his prophecy that makes the prophet, then he to whom our words to-night are tributary was a prophet.

From this point of view do not all of Dudley's varied quali-

ties seem to be but necessary parts of a consistent whole, the several facets of a single symmetrical gem? Is there danger? What more natural than courage, which implies little more than that the object sought is bright in the foreground of our mental vision, and the danger to ourselves overlooked in the background? Have I to correct your error? What more natural than tact and chivalry, which after all only imply that my course is directed chiefly by the thought of the effect which it will have on you? Is a task severe? What more natural than devotion to it, zeal, industry, tirelessness, for do not all these mean simply the prominence of the task and the enshadowing of the fatigue in the mind's eye? And does not this lead necessarily first to mastery of detail, which after all calls but for labor in thought; and through this to clearness of vision and of speech, which after all call but for complete mastery of the subject; and through clear sight in turn to originality, which comes from such familiarity with the matter in hand that we see possibilities and explanations and consequences which are hidden from the superficial observer. Or, again, do your interests and wishes oppose those of another? What can ensue but fairness, which after all implies nothing but that you see willingly and weigh fairly the interests, rights, and feelings of that other; that your ear listens more willingly to your duties than to your rights? And so we could go on through the list of his merits. They are the natural results of a common cause, the generous, unselfish character.

He never preached in words: he did not need to. His whole life was a practical demonstration of that which is best worth preaching.

Even to-day men ask "Is the golden rule a workable scheme? Can we live by it in our everyday human conditions?" The question carries less of doubt, and far less of denial, than ever before; but there it stands. "Must not charity begin at home?" The life which we honor to-night has its great value in its clear and decisive answer to these questions. Who ever suspected that Dudley did as he would not be done by? Who ever questioned that his life was in the highest degree successful both for himself and his employers? He might indeed have exacted more money from the world. "Gold and iron are good to pay for iron and gold." But the happiness and elevation of such a life as

his; the honor it unwittingly brought him; its guileless power, of which this meeting is but one speaking witness among a hundred which testify, eloquent in their silence—these things are no more to be weighed against money than is the life of wife or child.

We rejoice in having known him because he was what we would fain be; because he held up to us the best in ourselves, and showed us that we can live by that best: because he proved that practical worldly success of the highest kind, far from being hindered, was actually helped by loving obedience to those two great precepts on which "hang all the law and the prophets."

CHARLES B. DUDLEY AS A MENTOR.

By B. W. Dunn.

Mr. President, Ladies and Gentlemen:

My too short personal acquaintance with Dr. Dudley was limited to the last five years of his life, but during this time it was my fortunate privilege to meet him often and to discuss in affectionate intimacy subjects of mutual interest to us. My indebtedness to him, combined with the love and respect which I cherish for his memory, makes it more than difficult for me to speak of him analytically or dispassionately on this occasion.

If a mentor be defined as a mental guide, possessing a wider range of useful information and a personal magnetism strong enough to evoke with compelling force the admiration, confidence and affection of his associates, the term describes with peculiar aptness the relation of Mr. Dudley to many who now mourn his death.

We are here not simply to pay honor where honor is due, not merely to exalt the memory of a deceased comrade. It affords us some consolation to bear witness to the value of his loyal services to this Society, to the Pennsylvania Railroad, to the railway service of the United States, to the manufacturing industries that supply railway material, to the safe transportation of dangerous materials, to the legions of his friends and admirers. It is our duty to perpetuate for the benefit of ourselves, and of future generations, the uplifting force of his example. To this end it is appropriate to sketch, even though it be in skeleton form, his achievements in some one of his many activities. My personal knowledge of his work is confined almost exclusively to his efforts to promote safety in the transportation of dangerous articles.

When the statement is interpreted properly, I consider it a compliment to Dr. Dudley's memory to proclaim that, in the modern sense of the term, he was not an expert in any branch of science. He was too eager to absorb and assimilate the essential facts and principles of many professions to permit the devotion to one of that concentrated application so necessary to merit classi-

fication as an expert. An expert is necessarily narrow-minded and Dr. Dudley was anything but that.

Among the specialties in chemistry, we find the chemistry of explosives, in which a remarkable development of new facts, theories and principles, has taken place since Dr. Dudley, as a railway chemist, was asked nearly thirty years ago by the President of the Pennsylvania Railroad to investigate and define the risks that attend the transportation of explosives. He visited at that time the principal factories, witnessed tests, and brought samples to his own laboratory for analysis and further investigation of their properties. He familiarized himself with foreign rules and practices and prepared a short but comprehensive set of regulations for the transportation of explosives. Previous to this time a special permit had been necessary to ship explosives by rail and it was characteristic of Dr. Dudley to recognize thus early the obligation of a common carrier to transport anything that is essential to commerce. He foresaw for explosives a rapidly expanding field of usefulness in all branches of development and construction work, and he had the courage to recommend that their transportation risks should be assumed as a public duty. The rules that he proposed in the early eighties to minimize these risks, and his subsequent revision of them, were adopted by many of the railroads in the United States, but no special provision was made for enforcing them.

By 1905 the amount of explosives offered for transportation had increased beyond even Dr. Dudley's earlier estimates and the list of disastrous explosions during transit had attained alarming proportions. It was time for the next logical step, the cooperation of all railway lines to secure improved and uniform regulation of this dangerous traffic. A committee was appointed by the American Railway Association and Dr. Dudley was the most active member of it. He prepared for it an able technical report on the classification and characteristics of explosives and made another revision of his previous work, which was recommended by the committee and approved by the Association as a set of rules for adoption by all of its members.

Another important step remained, and Dr. Dudley worked zealously to impress upon all the fact that "regulations do not enforce themselves." The committee of which he was such a

prominent member secured in 1906 the approval of the Association for the organization of a "Bureau for the Safe Transportation of Explosives and Other Dangerous Articles" to be charged, in the interests of all of its members, with the inspection and the educational work necessary to enforce the regulations. This bureau was organized in November, 1906, and Dr. Dudley served as president of it from that time until his death. The bureau represented a novel experiment in railway administration. Its inspectors were not vested with any independent authority but they were given the right to inspect records and observe practices. They described the dangers, explained the rules and the reasons for them, and reported results. Any disciplinary action necessary to correct errors was taken by the officials of the line under inspection. The support given by these officials was in direct proportion to the confidence inspired in them by the inspectors.

Dr. Dudley was the solicitous mentor and the affectionate grandfather of the organization. No new step was taken without consulting him and it was seldom that any important action did not bear the impress of his wise counsel. It was evident to all that he worked for the success of this bureau as the crowning event in his extended career of usefulness. Long journeys, too fatiguing for a man of his years and state of health, were made frequently by him in its behalf and his last illness followed such a trip.

The regulations introduced by the bureau caused restrictions on both the shipper and the carrier, restrictions that increased the cost of preparing and transporting shipments. The difficulty in securing anything is proportional in some degree to the cost, and this applies especially to cooperation that is sought from naturally antagonistic elements. On more than one occasion the persuasive magnetism of Dr. Dudley's eloquence was felt in meetings of the American Railway Association, in conferences between representatives of the bureau and prominent shippers of dangerous articles, in hearings before committees of the national legislature and before the Interstate Commerce Commission. His was a disinterested plea for the promotion of public safety, the force of which was intensified by his personality.

We hear a great deal at the present time of federal regulations of interstate commerce and the subject will be of increasing interest and importance to railway officials. Whatever one's opinion may be of the wisdom of this regulation, the handwriting on the wall has been legible for some time to those willing to read it. Dr. Dudley was opposed in a general way to governmental control of railway operation, but he was quick to see the advantage of this control in the transportation of dangerous articles, and to him more than any other is due the passage by Congress in 1908 of the law that invested the Interstate Commerce Commission with authority to prescribe regulations for the interstate transportation of explosives. This advantage is not due to the possession by this commission of the technical information necessary to the framing of wise rules. On the contrary its members would be the first to acknowledge that they are lawyers as a rule and know little of the chemistry of explosives. It rests rather on the basic principle that we need some disinterested authority to adjudicate all disputes. An erroneous decision is better than none. The advocate of what is reasonable and right will secure justice from the commission sooner and with less expense than through a contest *à outrance* with his antagonist. We all know that public utilities differ materially from private enterprises and that the people, in whose hands the power rests, have decided to subject to governmental supervision the decisions of railway officials relating to rates and regulations. Those of us who are acquainted with these officials know also that their decisions are based upon their honest conceptions of equity and justice. My experience in working with Dr. Dudley to secure the cooperation of manufacturing shippers of dangerous articles to promote safe transportation has furnished abundant evidence of the willingness of shippers to submit to sacrifices when sound arguments are furnished to establish the necessity for these sacrifices. Experience has also demonstrated the wisdom, the honesty of purpose and the unimpeachable integrity of the Interstate Commerce Commission. What better foundation can be furnished for the optimism that sees in the trend of modern events the dawn of a new era of peace and stability?

Having suffered in his younger days the disadvantages of poverty, Dr. Dudley kept a warm place in his heart for the rail-

way laboring men. He lost no opportunity to extend his personal acquaintance with them and their problems. He attended and addressed, in the true spirit of a mentor, their various meetings, and he devoted many hours of his valuable time to the provision at Altoona of a suitable library for their use.

Speaking of the advantages of federal control suggests the unsatisfactory condition at present of the public utility labor problem. Labor organizations have done more than legislatures to curtail the authority of operating railway officials, and the day is not far distant when it will be necessary to invest a non-political and federal commission, or court, with the authority to adjudicate, and not simply to compromise, labor disputes. When this is done it should be made a criminal offense for any employee of an interstate public utility corporation to attempt to interfere with its efficient operation in public service by that collective act known in the railway service as a strike and in the military service as a mutiny. Without courts to decide on their merits the disputes of individuals relating to property rights, our land would be filled with strife and bloodshed; and yet we have made no such provision to prevent the waste of the country's energy in the struggles of railway labor and capital, struggles that necessarily involve more innocent than interested parties.

A general railway strike, that could be declared at any time by the leaders of labor organizations, would cost the country more and would disturb it more than would a first-class war of equal duration. It requires an act of Congress to declare war. Should it be possible for a greater disturbing power to be exercised for selfish purposes by a small number of our citizens? And yet who can blame the laboring man who honestly believes himself to be treated unjustly and who has no other recourse than to strike? This is an example of the class of problems that fascinated Dr. Dudley and it was an inspiration to good citizenship to note his efforts to form sound opinions. Knowledge, humility, honesty, unselfishness, perseverance, and "good will to all men" were interwoven in the fabric of his optimistic nature.

In conclusion, I cannot refrain from an allusion to his domestic life. A veritable reservoir of love and affection, fitted as few men are, to be an exemplary husband and father, it was his misfortune to live for years in domestic solitude. This added mate-

rially to his mental accomplishments, but the sacrifice to his humanity can be appreciated only by those who knew him intimately. Let us rejoice that he lived long enough not only to realize many of his ambitions, but also to enjoy for a few years at least the companionship of a wife who did all that an intelligent, sympathetic and loving woman could do to fill his last years with happiness. She is entitled to all the consolation that can come from the consciousness of a duty well done and from pride in the knowledge that at the altar of her affections the Doctor offered a pure heart and a mature mind.

CHARLES B. DUDLEY AS A CITIZEN.

By W. H. Schwartz.

The late Dr. Charles B. Dudley was related far more intimately to the municipal life of the city of Altoona than the average citizen of that town comprehends. For the greater part of his work was done so quietly and unobtrusively that few identified the man with the result. He never bothered himself about fame. By the hard work of laborious days and nights he sought results, not notoriety. Few men have done so much in so many different directions for their communities as Dr. Dudley did for Altoona. Few have been so anxious to bring things to pass and so indifferent about personal credit.

Dr. Dudley became a citizen of Altoona in 1875. He retained that citizenship until his lamented death. When he located there the city government had been in existence about seven years. The town was unkempt, the streets unpaved, the water supply insufficient, the street lighting inadequate, the annual receipts meager, the credit of the corporation poor, the pride of the people in their town practically non-existent, the school system primitive, the sidewalks made of planks, the people without the vision which must come to those who mean to win in the race for supremacy. In the generation that intervened Dr. Dudley was a part of Altoona's municipal life in a very vital sense. It would be difficult to name the promoters of the tremendous material, social, intellectual, spiritual advance that has come to the city with the passage of the years without including him as one of the number. He was always a busy man; he was charged with an arduous task; but he abounded in energy; more than to any other material thing one might compare him to a great dynamo, filled with splendid and exhaustless power, a power gladly devoted to the benefit of his fellow men, a power utterly devoid of the sordid or selfish element.

Many professional men decline to bother about the daily iife of the community in which they do their work. They sniff at the practical politician and mourn over the perversity of the

average voter, but neglect to do anything of practical value. Dr. Dudley was not that sort of a reformer. He knew what the city needed and he struck effective blows in the right direction at the proper time and in the wisest possible way. He sought to know every new editor, city editor or reporter who came to town. He had a habit of casually dropping into the newspaper offices or stopping newspaper men on the street, freely expressing his convictions concerning municipal or other problems. There was so much sincerity about the man, so much vitality, so much downright moral earnestness, that he became in some respects the most influential newspaper man the city possessed, although he seldom wrote a paragraph. He exerted his influence by proxy. Getting a good idea concerning some matter of local interest, he dropped it into the fertile soil of a responsive editorial or reportorial brain and lo! the work was in process of accomplishment. The power for usefulness of a busy professional man is increased manifold if he annex the people who make the local newspapers to his staff of workers. Men like Dr. Dudley not only enlarge their personal influence for good by getting into touch with their home editors, but also prove a veritable inspiration to those who make the newspapers from day to day.

The Altoona Mechanics' Library and Reading Room Association is one of the pioneer institutions of the " Mountain City." It was organized in the early 50's, some of its original officers and members having at a later period acquired international fame. Andrew Carnegie was one of the early secretaries. Dr. Dudley became interested in the association soon after taking up his work in Altoona and in 1880 was elected a director. It is not too much to say that during the rest of his life he devoted as much time and energy to the development of this institution as the ordinary man gives to his regular business. Loving books as he did with all the ardor of a scholar, and feeling that a community which keeps itself in touch with the best work of the great men and women of the ages is more likely to bring things to pass than one which seldom devotes a thought to things of the intellect, he labored unweariedly, but with great tact and wisdom, to bring the library into the conscious daily life of the people. The library was the object of his unceasing and affectionate solicitude. He spent much of his spare time in consultation with the librarian and others who were in-

terested in the extension of its beneficent work and for years was an influential member of the committee that selected the books and periodicals annually purchased for the use of the members. During the thirty years of his identification with the library it changed its location thrice, each time occupying a larger and more commodious home; its membership increased from 98 persons to 1,445; the number of volumes on its shelves grew from 3,209 to 46,217; the methods of its administration were largely improved, so that when his connection with it ceased it was ministering not only to the intellectual pleasure of thousands of adult readers, including the aged and infirm pensioners of the Pennsylvania Railroad Company, but also to the instruction and profit of several hundred pupils of the public schools. Dr. Dudley would be the last person to claim credit for all the improvement that has taken place in the manner and methods of this great library and reading room, for he had some noble helpers who are still carrying forward the splendid work begun more than half a century ago, but it is the testimony of all who knew anything concerning his unceasing and unselfish labors in this particular section of his chosen life-work that he was the mainspring of most of the improvements undertaken during the period of his active connection with the institution. Officers and patrons will long cherish pleasant recollections of his practical labors for the enlargement of the library and the extension of its influence. For many a year to come it will enshrine his memory more completely than any other institution in the city of Altoona. The library for some years provided an annual entertainment course, consisting of lectures and concerts, each member having free admission for himself and one other. In later years this feature was discontinued and the library association, led by Dr. Dudley, threw the weight of its influence on behalf of University Extension, several valuable courses of lectures on instructive themes having been delivered. There was no phase of the intellectual life of the city in which Dr. Dudley failed to be a leader and an active and enthusiastic force for good. Many an ambitious boy or girl has just reason to bless his memory.

When the city of Altoona undertook to organize a local board of health nothing was more natural than the appointment of Dr. Dudley as a member. That was his first and last public office.

He received no remuneration for his services, but it was entirely characteristic of the man that he gave himself utterly to the work of organizing the board, creating rules and regulations and working long hours to educate the people to protect themselves and their households by personal precautions. When an epidemic of small-pox visited the town he worked with all the energy of his body and mind to prevent its spread and end its ravages at the earliest possible moment. While he retained membership on the board he was its chief reliance. His knowledge and his wisdom were depended upon by his associates, and they were freely and gladly given. Altoona to-day has one of the most efficient boards of health in the commonwealth. The influence of Dr. Dudley was a potent factor in producing this efficiency and nobody more surely than the existing board realizes that "he being dead yet speaketh." What he did to decrease the annual rate of mortality, or to promote the comfort and health of the inhabitants, will never be fully known.

His services as a member of the board of health were supplemented by invaluable assistance to the friends of progress in the battle royal over the proposed enlargement of the city water supply in 1891. Situated directly under the shadow of the Alleghenies, the city of Altoona is so near the sources of the streams furnishing her water supply that the problem of securing an ample quantity had become a very urgent one. The rapid growth of the town, together with the wasteful methods employed, made it manifest that the small reservoir then existing at Kittanning Point would have to be supplemented by a much larger supply. The suggestion that a larger reservoir be constructed at Kittanning Point was taken up by the progressive citizens, of whom Dr. Dudley was a leader. Bitterly antagonized as the project was by a powerful interest, the timely services of the Doctor by way of collecting facts and putting arguments into the mouths of the newspaper men who favored the proposition, aided mightily in turning the tide of public sentiment in its favor.

Wisdom is justified of her children. Only those who passed through the bitter controversy which raged about the proposition to construct the great reservoir can realize the fierceness of the struggle. All the newspapers save one were arrayed against the plan; a very powerful combination controlled the city councils

for a time and succeeded in delaying action; plausible arguments were presented to the common people against the project. Ridiculous as they seem now, in the light of experience, they had influence then, and if the friends of the proposed method of increasing the water supply had been without the earnest and enlightened aid of men like Dr. Dudley the city would have been dwarfed in its physical progress and greatly harmed. A man of knowledge concerning the very problems involved in this urgent controversy, Dr. Dudley spared neither time nor labor in the preparation of an array of impregnable arguments which were duly presented to the people, both in the form of handbills and by newspaper articles, so that when the vote was taken upon the proposed loan, providing funds for the construction of the reservoir, the people voted yes by a very decisive majority. The reservoir has fulfilled the fondest expectations of its friends, so that the citizens of Altoona have on two separate occasions since voted sums of money aggregating $600,000 for the construction of a very much larger reservoir to be known as Lake Altoona and now in process of construction. So completely have the predictions of Dr. Dudley been realized concerning the practical utility of the impounding reservoir, that not a whisper of opposition or criticism has been heard since, and the latest reservoir project has received pretty nearly unanimous support. The result of this controversy shows the immense value of such men as Dr. Dudley to the communities in which they live.

He was always a busy man. He might have immersed himself in his special work and permitted municipal matters to drift. Many do. But he was not built that way. He possessed a peculiarly unselfish mind. The voice of duty was to him the command of God. He was not disobedient to the heavenly vision. He spoke out of an abundance of knowledge in a very practical manner and at the right moment. Speaking as one having authority, his speech had power, so that mighty results were accomplished.

A man like Dr. Dudley was inevitably interested in the public school system of his city. He never served as a school director, but he was always profoundly interested in the personality of school officers, whether directors or superintendents. He was a good friend to the aspiring teacher and was glad to do what he could to help that teacher gratify any laudable ambition. He was fertile in practical suggestions to superintendents and teachers concerning

possible improvements in methods of instruction or administrative policy, and the boys and girls who really wanted to know never had a better friend than he. In this important field of endeavor, too, he found time at irregular intervals or in crisal hours to discuss the situation with newspaper people, displaying his customary breadth of view and comprehensiveness of vision. Here, too, he was as quiet and retiring as in other matters, pushing his ideas to the front but concealing his personality.

In the realm of practical progress the Doctor was a true helper of his city. He was one of the promoters of the City Passenger Railway enterprise which started as a horse line before the wonders of electric progress had begun to dawn upon the country. He was a director of that primitive enterprise and one of its most active friends until it was transferred to other hands. He had great faith in the future of Altoona and possessed property in the city and vicinity. In the city's social life he was by no means an unimportant factor, finding time in some marvelous manner for participation in more than one important social function and having been a member of the Altoona Tennis Club, the Altoona Cricket Club, and of the Juniata Club, a strong social organization which flourished for some years. At the disbandment of the latter he was instrumental in having the surplus funds, about $1,000, given to the Altoona Hospital, another of the city's institutions in which he ever displayed a marked interest. In fact there does not seem to have been any important phase of the city's life in which he did not play an important part. In the lives of his fellow men he was also deeply interested and scarcely a day passed that did not find him quietly doing a substantial service to a workman who at the moment needed just such help as he knew Dr. Dudley would gladly render to any who needed a friend.

Let me briefly sum up the relation of Dr. Dudley to the life of the city in which he resided for the greater part of his active life:

First: He was a very busy man, charged with the performance of important and intricate duties for a great corporation; and yet there was never a time when he was so busy that he could not spare a part of his time for the public good.

Second: The nature of his professional duties involved the expenditure of much time and thought; but the problems con-

fronting the city were never so complex that he declined to consider them.

Third: As a director of the Altoona Mechanics' Library and Reading Room he constantly exercised a potent influence upon the intellectual life of the people. This was reinforced by his activity in University Extension work and his interest in the public schools.

Fourth: He constantly kept in touch with the newspaper men of the town. He never bored them, never stayed long enough to become a nuisance. His suggestions were put in an attractive way and bore fruit in stimulating articles which reached the people and caused them to think.

Fifth: In every crisal hour of the city's life he was ready to take off his coat, roll up his sleeves and go to work on behalf of the right. And because of this splendid trait he impressed his ideas upon his fellow citizens and brought things to pass.

Sixth: He was always interested in municipal politics, never as a partisan, always as a patriot. His influence was constantly exerted in the direction of better municipal government.

Under the circumstances the death of Dr. Dudley was a positive calamity to the city of Altoona. It was a far greater bereavement than the rank and file knew, for he accomplished results so unobtrusively and so largely through others that the real man was quite unknown to the generality of citizens. In most respects his life as a citizen of Altoona is one which can be commended unreservedly to the close imitation of his professional brethren. Too often they lack in that zeal, that devotion, that ardor for the city in which he excelled.

Because of the largeness of the theme and the time limit, no reference has been made to the activities and the splendid example of Dr. Dudley as a citizen of the commonwealth and the republic. Here also patriotic endeavor marked his career.

May his like increase!

CHARLES B. DUDLEY—A PERSONAL TRIBUTE.

By Robert W. Hunt.

The duty of closing this series of eloquent and affectionate tribute to the memory of our loved friend and fellow member falls to me. Others have spoken of him as railroad official, chemist, metallurgist, mentor, and citizen—my poor words are to be a personal tribute. I would that the gratifying task had been entrusted to some one better equipped than I, but, while my lips may lack power to express in fitting words the affection of the heart, I know that no one could feel more sincerely the high meed of praise and love which should constitute such a tribute.

Dr. Dudley's life was one of varied experience and many sides. His character was rugged, and yet he was so constituted that, while never losing sight of the desired goal, and never straying from the straight road leading to it, he could, at the same time, smooth the difficulties of the way by the sweetness of his persistency; which was ever present as evidence of his manifest honesty, and yet tempered by charity for, and magnanimity toward those who differed with him. His many years of experience in his official railroad capacity brought frequent opportunities for the exercise of such attributes, and that school prepared him for the duties incident to the Presidency of our Society. And it is undoubtedly true that without the exercise of such characteristics, and the great amount of time given to its affairs, its successful formation and subsequent useful life would have been impossible. When the Society was first formed, it was generally feared that it would become a manufacturers' organization, and therefore it was with hesitancy that others gave to its deliberations and recommendations unprejudiced consideration. I doubt if there was another man under whose leadership the Society could have so quickly been made successful. Dr. Dudley's whole business career had been as the representative of the consumer, yet he had always made manifest his endeavor to be fair to the maker. Hence, the confidence which both sides had in him. There might

be, and often were, differences of opinion, but never doubt of intelligence or honesty of purpose.

His country's call came to him while yet a boy at school, but the response was prompt, and he enlisted to play a man's part in the greatest and bloodiest drama of all time. He enlisted at the age of twenty as a private in the One hundred and fourteenth Regiment, New York Volunteers, and gave about three years of service, taking part in seven battles, and enduring many hardships. In the battle of Opequon Creek, fought on September 19, 1864, he fell severely wounded by a bullet.

He offered all he had upon the altar of his patriotism, and gave of his life's blood that the nation might live. His wound rendering further service impossible, he went back to his studies, and to bear to the grave the bullet and the lameness which was his greatest decoration of honor. That crippled youth did not return to enjoyment of petted adulation and ease—far from it; it was to take up a bitter fight against restricted means that he might complete his education, and in spite of every obstacle and the lost time, he with characteristic persistency could only be satisfied by a thorough education. He won, as he always did; and, instead of coming from the conflict soured and embittered, he emerged with a developed, mellowed, charitable, and most lovable character—"With malice toward none, with charity for all." Was he not worthy of all good things which could come to him?

There have been in the history of American technical societies but few such incidents as this to-night, and all of them have been held in the honor of not only intellectually great, but of also lovable men. They require response from deeper, warmer feelings than can emanate from the mere intellect. Love must call—and to-night our love answers.

Dr. Dudley was an honored and active member of over sixteen scientific societies of both this country and Europe. His contributions to their papers and discussions were numerous and always of forcible value. He only spoke when he had something to say, and then said it well. How fortunate it was that his European trip of last year as our representative should have brought him the honor which he no doubt regarded as one of the greatest of the many which had come to him. Indeed "he died full of honors."

We cannot again in this life listen to his hearty greeting, feel that warm clasp of his firm hand while looking into those honest, kindly eyes. The knightly spirit has preceded us across the border into the great unknown; but we believe, we know, that the best of whatever is there, is now his. The parting came for us all too soon, and, if so to us, his friends, what to that dear comrade of his, who made his later years so happy? Their life together was short, but oh so happy, and what a blessed inheritance of respect and love he left to comfort her!

He was called while yet in the full power of his great abilities, with his whole being in sympathy with the duties of his life and love for his fellow men. After all, is not such the best time to go?

The sad parting came amid the shadows of the evening of the unknown, but, as certainly as there is a great and most just All-Powerful One, shall we, in what will be to our lost one but a little while, be greeted by his bright and joyous spirit in the glorious morning of our everlasting day.

AMERICAN SOCIETY FOR TESTING MATERIALS.

AFFILIATED WITH THE
INTERNATIONAL ASSOCIATION FOR TESTING MATERIALS.

PROCEEDINGS.

This Society is not responsible, as a body, for the statements and opinions advanced in its publications.

REPORT OF COMMITTEE A-1 ON STANDARD SPECIFICATIONS FOR STEEL.

Committee A-1 did not find it necessary to hold meetings during the past year. Its report to the Society is accordingly limited to the following report of its Chairman on the Copenhagen Congress of the International Association for Testing Materials, held September 7-11, 1909, with special reference to the progress there made towards the ultimate establishment of international specifications for steel products.

REPORT ON THE COPENHAGEN CONGRESS, INTERNATIONAL ASSOCIATION FOR TESTING MATERIALS.

The Fifth Congress of the International Association for Testing Materials was held in Copenhagen, September 7-11, 1909. His Majesty, King Frederick VIII of Denmark, graciously consented to be the Patron of the Congress. His Royal Highness the Crown Prince Christian of Denmark accepted the office of Honorary President and read the opening address. The Organization and Reception Committees were composed of the government officials, leading engineers, and manufacturers of Denmark. Delegates were sent to this Congress by the leading governments of the world. Your Committee was honored by the appointment, at the hands of the President of the International Association, of your

Chairman as one of the Honorary Presidents of Section A on Metals at the Copenhagen Congress.

The International Association for Testing Materials has 2,200 members, Germany leading with 375, and the United States of America being a close second with 325 members.* The work of the Association has been confined mainly to methods of testing, and it was only at the recent Congress that a well-defined policy for the introduction of International Specifications was adopted, and the general plans for doing the work decided upon. This was brought about by the following resolution passed at the Brussels Congress in 1906, in connection with the report of Sub-Committee Ia:

"Committee Ia shall, on the basis of specifications recognized by the National Testing Associations of Germany, England, and the United States of North America, endeavor to establish uniform international specifications for the delivery of materials to countries that do not produce iron in any considerable quantities."

It was decided to consider for each class of material only one standard specification from each country, prepared by representatives of the manufacturing interests and an equal number of representatives from the railroad companies or of consumers' interests. The specifications decided on were as follows:

German specifications recognized by the Deutscher Verband für die Materialprüfungen der Technik. This is the German Branch of the International Association, and both manufacturers and consumers are represented in the preparation of specifications.

English specifications published by the Engineering Standards Committee, London. The main committee is composed of some 300 members, divided into 12 sections and 28 sub-committees. On these all the Engineering Societies are represented, as well as the Board of Trade, War Office, Admiralty, and India Office.

American specifications adopted by the American Society for Testing Materials. This Society has now over 1,200 members, and its specifications are recognized as the standards for this country.

*This report was written in the fall of 1909. The American membership is now (October, 1910) 449.

Sub-Committee Ia is composed of the following representatives:

For Germany: Dr. A. Rieppel, Chairman; Professor R. Stribeck; Direktor Vehling.

For England: Mr. F. E. Roberston; Mr. F. W. Harbord.

For the United States: Mr. Wm. R. Webster; Mr. Walter Wood.

Sub-Committee Ia held an official meeting in London on July 1, 1909, at which all three countries were represented, and reported to the Congress the following resolutions embodying their recommendations on the question of international specifications for testing iron and steel:

1. "That the work of preparing the different specifications which have been submitted to us for consideration, having been very thoroughly done in each country by committees composed of engineers representing both consumers and manufacturers, Sub-Committee Ia advises that the specifications of each country, recommended by the Deutscher Verband für die Materialprüfungen der Technik, American Society for Testing Materials, and the British Engineering Standards Committee, be recommended for use for material manufactured in that country on export orders.

3. "That copies of these specifications be sent to the Deutscher Verband für die Materialprüfungen der Technik, the American Society for Testing Materials, and the British Engineering Standards Committee, and that, when at any future time these Associations have under consideration the revision of their own specifications, they be invited to compare them with the corresponding specifications submitted from other countries and endeavor, wherever possible, to bring them into line with these.

4. "That the present Sub-Committee Ia be continued, and that the Member of Council in each country be made the *ex-officio* Chairman or Secretary of the respective meetings of that Sub-Committee.

6. "The Sub-Committee recommends the Commission to confer with the three Associations referred to above and keep them advised of the progress made, or suggestions offered, on modifications to bring the specifications more into line; that they also confer with the manufacturers direct, or through the Association, to induce them to roll trial orders of material under the conditions of the specifications of other countries, in order to find out how far these conditions can be introduced for export orders.

7. "That a standard drop-testing machine for rails be adopted in each country, as has already been done in the United States, in order to make the tests comparative."

These resolutions were reported at the Copenhagen Congress by Dr. Rieppel, Chairman of Committee I, and the following matter is quoted from that report:

"The Chairman of Committee I, at the same time Chairman of the Sub-Committee agreeing to these resolutions, begs to submit Paragraphs 1, 3, 4, 6 and 7 of the same for the approval of the Congress."

"In order to define more distinctly the lines for the future work of the Association in the domain of International Specifications, and to show the important economical advantages which could be brought about by them, the referee further desires to call the attention of the Congress to the following far-seeing suggestions of Mr. Wm. R. Webster, to whom the Committee is much obliged for working out the proposals which, after only slight alterations, have led to the above London resolutions.

"Mr. Wm. R. Webster points out in a letter that the Sub-Committee has been successful in advancing the work owing to their policy of using only one specification from each country for any class of material, and preferably the specifications of the branches of the International Association.

"As to America, a large committee, composed in equal parts of producers and consumers of steel, has succeeded after twelve years' work in equalizing the different specifications there existing and in establishing specifications which can be considered as good representative specifications of standard American practice.

"During this time all of those interested regarded the American Society for Testing Materials as a "clearing house" for specifications.

"What the International Association most needs is that the sections, the National Societies in all other countries, do similar work on specifications for their respective countries; then the International Association can likewise act as an international "clearing house" for specifications. If the work is carefully done by the committees in the several countries, it is not too much to expect that we will have a series of general international specifications, endorsed by the Association and recognized the world over by consumers and producers of steel and other metals. The most important features of these specifications will no doubt be very much the same, and will insure getting good, uniform, reliable material, no matter where the orders are placed.

"The minor requirements will no doubt vary, but the manufacturers in every country will only be asked to work under the requirements that they are perfectly familiar with.

"Under the conditions as indicated above, the purchasers of steel rails or other material in any part of the world would only have to consider prices and time of delivery, feeling that their interests would be fully protected by the International Specifications wherever the orders were placed.

"It is hardly necessary to say that the adoption of a well-defined policy on International Specifications will be of the greatest benefit to the Association and the National Societies (sections) of all countries; it is therefore to be hoped that the Congress agrees to the report of the Sub-Committee and to the plan of work suggested."

This report was printed in three languages and, all the members having received copies, was presented for discussion. Professor A. Martens, First Vice-President of the International Association, offered the following resolution before Section A:

"The Fifth International Congress welcomes the work of Sub-Committee Ia with pleasure and approves in general the principles laid down in the Congress Report VIII1 and decides: Commission I is invited to continue their valuable labors in cooperation with the National Societies and, if possible, to lay before the Sixth Congress definite proposals as to the basis of International Specifications for Iron and Steel."

This resolution was submitted to the Council and approved; subsequently, at the direction of the Council, it was submitted to the Congress and adopted at the final session.

Between the meeting of Section A and the final session of the Congress, an informal meeting of Sub-Committee Ia was held and all members interested in international specifications for iron and steel were invited to be present and to express their views as to how the work might best be conducted during the next three years; it being understood that each member was to speak for himself and not for any railroad, association, or government body.

The following reference to this meeting is quoted from Proceedings No. 15, February, 1910, of the International Association for Testing Materials:

"The problem of the international unification of specifications was, on the suggestion of Mr. W. R. Webster, of Philadelphia, informally discussed in the rooms of Section A, on September 9 at 5 p. m., by a very fully attended meeting. Mr. Webster took the chair in response to the general desire. It was once more emphasized that the different countries had first to agree upon uniform specifications, which had so far been done only in Germany, Great Britain, and America. In that case Committee Ia would, in each country and for each class of materials, have to deal with only one regulation, which would be recognized by a Testing Association consisting of producers and consumers (in countries which did not produce iron, only of the latter). The idea that the commissions of the separate National Associations should act after the manner of clearing houses for the specifications of their own countries, while Committee Ia would

be the international clearing house, met with general approval. It was also recognized that it would be possible, by comparison of such specifications and by their progressive adaptation to marked changes, to avoid hair-splitting regulations, and finally to arrive, if only in the course of years, at uniform specifications. It was further generally acknowledged that it was desirable to admit other countries to Committee Ia, in so far, of course, as these countries adhered to the above-mentioned conditions. The Secretary-General undertook to report to the Council on the cooperation of the representatives of such countries. Several speakers finally explained the actual state of the problem of the unification of specifications in their own countries."

Dr. Belelubsky of Russia claimed that standard specifications existed in his country and asked that they be considered with those previously taken up by the Committee. It was shown that he referred to the government specifications and it was suggested that these specifications should be submitted to a committee of at least ten engineers, half of whom were to represent the manufacturers and half the consumers; and that if this committee endorsed the specifications, they would be considered as requested. In other words, it was the sense of the meeting that both sides should be heard from on all specifications.

Mr. Leslie S. Robertson, Secretary of the British Engineering Standards Committee, who attended the Congress in an advisory capacity to the English delegates, explained how the work had been done in England, spoke of the satisfactory results already accomplished, and thoroughly endorsed the general plan of work outlined in the report of Sub-Committee Ia.

Dr. Charles B. Dudley, President of the American Society for Testing Materials, explained how the work had been done in this country, and said that of necessity the manufacturers of steel must know more about chemical and physical requirements of the steel to produce a uniform steel than the users; and on the other hand, the user of the steel must know more about its behavior in service than the manufacturer; and that it was only by having both interests represented on the committees that the best results could be obtained in deciding on requirements for standard representative specifications.

As a result of this informal meeting, there is now a better understanding on the part of those interested as to how the work is to be carried on and what the Association has undertaken to do.

It was shown that Committee Ia will have to be materially increased, many countries having expressed a desire to be represented on this important work.

There were also other informal meetings of the members of Committee Ia, held in Copenhagen, but unfortunately none of the German members attended the Congress.

Seven years ago, when the American Society for Testing Materials undertook to formulate standard specifications, it had only 175 members. The membership has in the meantime steadily increased, manufacturers as well as consumers having taken an active interest in this work. It is not too much to expect that the International Association for Testing Materials will show a corresponding increase in membership, now that the practical work of the introduction of International Standard Specifications has been undertaken at such an opportune time. Several of the members expressed the opinion that for the first time it had been shown them how practical work could be done by the Association that would be of great advantage to the manufacturers and consumers of all countries.

It was expected that the next Congress would be held in Russia, but there was so much delay in getting the consent of the different government bodies that an official invitation could not be extended to the Association. It was therefore decided to accept the invitation of the American Society for Testing Materials, and the next Congress will be held in the United States, in the fall of 1912.

The question came up as to whether government consent had been given for holding the Congress in this country. It was explained that it was unnecessary for us to obtain such consent, but in taking the matter up with our Minister at Copenhagen, he kindly helped us out with the following letter, which was presented to the Council, who received it with a vote of thanks to Dr. Egan. The letter was read at the final meeting of the Congress and received with applause.

AMERICAN LEGATION, COPENHAGEN.

September 10, 1909.

WILLIAM R. WEBSTER, Esq.,

Dear Sir:

Referring to our interview of to-day, I shall be pleased if you will advise the President of the International Association for Testing Materials,

that should it be decided to hold the next Congress in the United States, I will take pleasure in advising our Government at once and requesting that they extend every courtesy possible to the members in order that their visit may be both interesting and profitable.

Yours very truly,

MAURICE FRANCIS EGAN,
American Minister.

The report of Sub-Committee Ia, which is still in type and can be supplied as desired in French, English, and German, gives in parallel columns the summary of the specifications that were considered, viz., Structural Steel for Bridges, Structural Steel for Buildings, Steel Rails, and Steel Splice Bars.

Particular attention is called to Resolution 6, and it is hoped that trial orders will be manufactured in this country under the general conditions of the English and German specifications, in order to determine if any modifications can advantageously be made in the American specifications to bring them more nearly in line with the others.

Regarding Resolution 7, covering the drop-testing machine, it is expected that a description and cuts of the American machine will be published in the Proceedings of the Congress as a supplement to the report of Sub-Committee Ia. The English members report the greatest variations in the drop-testing machines in use in their country, as well as in the general conditions under which drop tests are made.

The work on International Specifications can only be carried on successfully along the lines indicated. Each country must first agree on uniform representative specifications for each class of material. Until this is done there is no use trying to harmonize the differences in the specifications of the various countries. The specifications of any country will not be considered by the Committee unless the engineers of that country get together on their own specifications.

The work that has already been done in the summaries of the German, English, and American specifications, shows that the differences on the main points are not as great as at first supposed. The Committee did not attempt to harmonize these differences, as their conclusions would not carry anything like the same weight as would be the case should the respective committees make the neces-

sary modifications in their own specifications in order to harmonize them. To do anything else would only antagonize the committees whose specifications were under consideration.

It is not too much to expect that international specifications will be submitted for approval at the next Congress in 1912. This can be done if the work is continued in a systematic manner on the present lines, and the necessary funds are provided for carrying it on in this country and abroad. Summaries of the specifications of each country should be tabulated and published in French, German and English, and sent to all members in order that the work may proceed continuously and general interest may be maintained. Specifications for ship material, boiler material, steel wire, etc., should be taken up in addition to those under consideration.

In order to show how the standardization of specifications is viewed in England, what is being done there, and how the movement is supported, abstracts from three important papers are given below.

I. From "Standardization and Its Relation to the Trade of the Country," by Sir John Wolfe Barry, Chairman of the Engineering Standards Committee and President of the Institution of Civil Engineers; delivered before The Institution of Engineers and Ship Builders in Scotland, at Glasgow, in 1908.

"In 1901, after considerable discussion, a committee was appointed by the Council of The Institution of Civil Engineers to consider the subject, and, as it was felt that the cooperation of the sister institutions would be of inestimable advantage, an invitation to nominate representatives on this investigatory committee was sent to The Institution of Mechanical Engineers, The Institution of Naval Architects, and The Iron and Steel Institute. All these bodies cordially accepted the idea as one worthy of earnest consideration, and a joint committee was thus constituted of delegates of the councils of the four institutions to examine and report on the proposal.

"Many of the chief industries in engineering manufactures are represented by official trade associations, and as in dealing with any particular subject it has always been the policy of the Committee to elect representatives from all parties, the Committee invited not only institutions such as your own and other kindred bodies, the leading consulting engineers and the chief manufacturers, to join them, but also secured the cooperation of the trade associations.

"To the main committee thus constituted falls the duty of guiding

and directing the work of standardization, the selection of the subjects to be dealt with, the passing of the reports, and last, but not least, the raising of the necessary and not inconsiderable funds to carry on the work.

"It also became apparent that the engineering industry of this country would profit considerably in many directions if standardization on a judicious scale were initiated in the nature of the materials as well as in the form of the manufactured articles. The many specifications differing often in unimportant and trivial details were in many cases involving much increased cost without corresponding advantage to the purchaser in the article produced. This diversity of specifications was placing our manufacturers at a disadvantage when competing with foreign firms, and cases were by no means infrequent in which purchasers, though insisting rigidly on specifications when contracts were given to firms in this country, were willing to accept less rigid conditions when placing their contracts abroad. Foreign manufacturers were often in a position to put forward, as alternatives, specifications and tests recognized in their own country, and were so enabled to tender at a lower figure than British firms who, not having any acknowledged standard, had to work to the divergent views of different purchasers.

"In other countries a good deal has been done in the way of standardization by various bodies, but in no country has the work been so systematically organized as here. The existence of one main committee to control the subjects dealt with, while each sectional committee is left at full liberty to investigate and deal with its own particular branch, enables the main committee to coordinate and unify the work in a way which is not possible if various bodies, practically independent of one another, were dealing with their own individual branches of engineering.

"The above will explain how the work has gradually grown from the original small committee appointed by the Institution of Civil Engineers and has become an existing organization of magnitude and importance, in which there are at present 39 committees with a membership of nearly 300.

"The following extract was contained in a letter, dated 1903, from the Board of Trade, when the Government informed the committee of their willingness to accord them financial aid:

> 'In conveying to the Engineering Standards Committee the decision come to by the Treasury as to the grant to be made, the Board of Trade desires me to state that they regard the work undertaken by the committee, including as it does the preparation of standard specifications for engineering works and of standard sections of rolled iron and steel, together with the standardization of parts of locomotives and electrical appliances, as tending to reduce both the cost of production and the time occupied in completion, and as being of the highest value to the country at large.'

"It may be of interest, also, to quote an extract from a letter received

in 1905 from my Lords Commissioners of the Admiralty, informing the Committee that

> 'The Admiralty are prepared to adopt the Specifications for Structural Steel for Boilers where steel of the tensile strengths therein referred to is required, also the Standard Sections, and, in so far as they refer to the specification above mentioned, the Standard Forms of Test Pieces.'

"The letter further states that

> 'As regards hull work, the cooperation of the Admiralty may be relied upon in the adoption, as far as practicable, of the recommendations laid down in the various findings of the committee.'

"A very important direction in which the Committee's work has been beneficial is that it has afforded an impartial meeting ground where the different and sometimes conflicting interests of designer, purchaser, and producer can be openly and thoroughly discussed. That this has been recognized may be evinced by the words of one of our leading manufacturers, who writes as follows:

> 'In our opinion one of the chief advantages of the committee has been the bringing together of those representing various interests which have been harmonized to the advantage of all concerned by the adoption of some degree of uniformity in designs and specifications. If for this reason alone, we think the work of the committee has been very valuable.'

"Such then has been and is the work of the Standards Committee, and it will be obvious that the cost of the preparation of the designs and specifications contained in over forty reports has been, and naturally must be for this class of accurate work, somewhat heavy. The total sum expended on the Committee's operations up to the end of the present financial year in March, 1909, will be approximately £25,000. The Committee have been enabled, by liberal grants from the five supporting technical institutions, from the government grant, by the sale of their publications, and by financial aid granted to them by leading railway companies, manufacturers' and trade associations throughout the country, as also from individuals, to meet the expenses thus far incurred; but some means will have to be devised for the continuance of the work on a reduced scale of work commenced but not completed, and also for dealing with any work which from year to year will be entailed in the revision of the standards and the preparation of any new standards which circumstances may demand.

"The commercial and technical sides of engineering are inseparably linked together, and whatever the perfection of mechanical methods of production in this country may be, unless the commercial side of the business is equally efficiently organized, there will be no adequate return. There were many markets which formerly were exclusively British, but in

which we no longer hold supremacy, because by quickness and dispatch, rather than through superiority of their material or workmanship, Germany and America have been able to beat us. Of course, there are markets in which we cannot hope to compete successfully on equal terms, by reason of imposts and protective duties, but the work which has been effected by the Committee should very materially assist us in keeping the trade of our Colonial Empire in the hands of the British manufacturers. If the Colonial Governments will insist upon all materials bought by them being to British standards, they will know that they are receiving good designs and high-class material, in both of which they can have entire confidence; while the manufacturer at home, knowing that the colonial orders are to be placed in accordance with the requirements of the British standards, will be sure of what is expected from them, and be able to give prompt and speedy delivery at moderate prices.

"The question is a national one, and cannot be regarded in any narrow way. Its financial importance and magnitude are but feebly indicated by the few figures which I have given merely as examples, for in truth, Standardization affects the whole engineering trade of the Kingdom and Empire. The movement towards standards and an intelligent system has already produced the most gratifying results, and many more will follow. In these effects all classes are closely interested, and none more than our vast working population, whose well-being, and I might say very existence, depend on Great Britain being well equipped and up-to-date in the acute trade rivalries of the world."

II. From "Standardization and Its Influence on Engineering Industries," by Professor William C. Unwin, Vice-President of the Institution of Civil Engineers; delivered before the students of The Institution of Civil Engineers in Session 1908–09.

"Already, in Germany and the United States, some considerable steps had been taken in simplifying and systematizing the manufacture of things of general application, and standards of form and quality were accepted by general agreement. In this country we might have gone on in a characteristically individual and unsystematic way, but for the increasing pressure of external competition. It has become essential to the prosperity of our industry that cost of production should be reduced.

"Very early in the discussions it became clear that a unification of the general conditions imposed in specifications for material, especially for steel, and a reduction to uniformity of the tests of quality required, were of the greatest importance.

"When it is considered that six and one-half million tons of steel are manufactured annually, it can be realized how troublesome would be divergent specifications as to strength and chemical composition involving alterations of manufacturing processes for different orders. One

firm engaged in the supply of material stated that they had before them sixteen slightly different specifications for steel boiler plates, thirteen for steel plates, eleven for copper plates, nine for boiler tubes, and fifteen for steel forgings. With such a variety of specifications, manufacturers were unable to anticipate and provide for future demands, and it is impossible to suppose that such a variety of conditions of reception were necessary or rational.

"In the case of ship material, manufacturers were under a special restriction, for the material has often to pass the tests imposed by two different registration societies, and the limits available in that case are extremely narrow.

"There can be no doubt that, in the past, many specifications have been drawn up in a very loose way and with little knowledge of the effect of various restrictions in hampering the operations of manufacturers.

"The Standards Committee have now drawn up a series of complete specifications for different classes of material. These cover all the necessary checks on quality, without prescribing the merely commercial conditions of supply which are best arranged between manufacturer and client.

"No manufacturer objects to adequate testing and inspection of material, but all manufacturers do object to have to meet different tests for the same material supplied to different users, so that the material made to comply with the requirements of one engineer would be rejected by another. Clearly the conditions imposed in specifications should be the minimum required to protect the purchaser, and it is irrational to suppose that discordant conditions of testing are likely to secure the best quality of material. It is purely a matter of experience and investigation to determine what are the best tests for any given material, and unnecessary or discordant tests hamper the manufacturer, defeat the object of securing the best material, and add to the cost at which material can be supplied.

"*Chemical Analysis in Specifications for Steel.*—Very strong differences of opinion exist among engineers and steel-makers as to whether a partial or complete chemical analysis should be included in standard specifications. As to the necessity of mechanical tests there is no dispute. The question is more difficult because steel is a very complex material, the properties of which depend not so much on individual constituents as on the combination of different constituents. The steel-maker himself must rely on chemical analysis in the control of all his operations, and it is his special business to discover the best combination of constituents in steel, manufactured by given ores and processes, to secure the best mechanical properties. But the question remains, whether the steel-maker should be free to use his knowledge and experience in obtaining the best product from his materials and in satisfying the mechanical tests required, or whether the engineer for his own protection should specify a more or less precise analysis of the steel, in addition to the mechanical tests which give direct information as to the physical prop-

erties of the steel. Many engineers using large quantities of steel require no chemical analysis at all. The Admiralty and the Ship-Registration Societies have not generally required any chemical analysis. Some engineers lay down limits only for particular constituents, such as phosphorus and sulphur, generally recognized as prejudicial. Some require to be furnished with complete chemical analyses.

"It is not unimportant that there must usually be delay in accepting a consignment of material, if a chemical analysis is required in addition to mechanical tests."

This subject is pursued much further in this paper and arguments are advanced in support of the other side of the question. It is not necessary to quote this matter here, as in this country the general opinion is overwhelmingly in favor of prescribing both chemical and physical requirements in specifications in order to secure good, uniform, and reliable material.

III. From the Presidential Address by Mr. James C. Inglis, President of the Institution of Civil Engineers, delivered in 1909.

"With regard to the Engineering Standards Committee, to which I have referred, it is impossible to overestimate the value of the results obtained by that body with the aid of its numerous Sub-Committees. It is now some eight years since definite steps were taken to effect standardization, and in that period the investigations of the various Committees have enabled members to somewhat realize the unsystematized condition of British manufacturing and constructional practice, the vast interests involved, and the extraordinarily wide fields served by British manufacturers. It is only when these matters are properly appreciated that an estimate can be formed of the extent of the labors of the Standards Committee.

"I would refer you here to the interesting report just issued by the Committee, and would endorse the opinion that its work is by no means ended.

"Immensely valuable as the work has already proved to be, it must be regarded as largely in the nature of a preliminary effort, paving the way to what will probably form a more difficult and important task, namely, the settlement of International Standards, particularly with America and Germany, the two countries in which standardization has been most highly developed.

"Naturally, different parts of the world come under the predominating commercial influence of one or other of the great industrial countries, and this carries with it a demand for the standards of manufacture (shape or sections) of that predominating country. For instance, in Germany,

the steel manufacturers' rolls are being cut for English standards, while in England, I am sure you will find, our British manufacturers are being pressed to cut German shapes. The same feature applies to American commerce.

"Already an International Association for Testing Materials is at work, and its proceedings for August last contain the report of the Sub-Committee on the 'Establishment of International Specifications for Iron and Steel.' The Standards Committee is represented in that Association, and it is to be hoped that the great importance of the issues involved will ensure not only a speedy determination of International Standard Specifications for iron and steel, but that this will be followed by International Standard shapes and sections, and ultimately by standard sizes and fittings for all engineering products of world-wide use which an International Committee can determine upon.

"The extension of transport facilities and the rapid development of numerous industrial States, coupled with universal demand for industrial products, endow the question of International Standards with an importance almost political. It is an urgent matter which British engineers should strive to further to the utmost extent of their opportunities, which at the present juncture are great."

The American Society for Testing Materials has decided to issue a Year-Book, which will contain all the standard specifications. It will doubtless be a welcome surprise to most of our members to see how much has already been accomplished without any outside assistance or financial aid. Our work compares very favorably with that of the Standards Committee of England, who have already expended over $125,000 in their work.

Respectfully submitted on behalf of the Committee,

WILLIAM R. WEBSTER,
Chairman.

EDGAR MARBURG,
Secretary.

ADDENDUM.

The action of the Copenhagen Congress has created world-wide interest in the subject of international specifications, as is shown by the resolutions adopted by The International Railway Congress at Berne in July of this year. The resolutions are as follows:

1. "The Congress expresses the wish to have reported at the next Congress, with the collaboration of steel manufacturers, on the state and progress of the work of the International Association for Testing Ma-

terials dealing with the comparison of the specifications for iron and steel.

2. "The Congress further resolves in connection with the conclusions on the question of steel and special steel, that it is desirable to take into consideration the prescriptions (specifications) drawn up by the International Association for Testing Materials, for the inspection of steel material."

This action is particularly gratifying, not only because the active interest of the railways of the world in the movement for international specifications would be highly advantageous, but also because, as the chief prospective beneficiaries of such specifications, the railways may reasonably be expected to lend their full support to this movement.

W. R. W.

REPORT OF COMMITTEE A-3 ON STANDARD SPECIFICATIONS FOR CAST IRON AND FINISHED CASTINGS.

The Chairman respectfully reports that he has called upon each sub-committee, to learn whether any changes are to be suggested in the present standard specifications. With the exception of the Committee on Specifications for Locomotive Cylinders, they unanimously report that at this time they desire to bring forward no changes in the present specifications. It was hoped that the Committee on Locomotive Cylinders would have certain minor changes to be proposed in that specification ready for submission to this meeting, but these have not as yet been put into shape.

The following is a report on the action regarding Cast Iron taken at the Copenhagen Congress.

REPORT OF WALTER WOOD, MEMBER OF SUB-COMMITTEE Ia, IN REGARD TO INTERNATIONAL SPECIFICATIONS FOR CAST IRON.

Informal meetings of those members of Sub-Committee Ia who were present at Copenhagen, together with the English and American members of the Congress interested in cast iron, were held from September 6 to 9, 1909, to consider the specifications that had been submitted for cast iron.

The following specifications were presented for their consideration

From Germany:* Pipe Castings, Castings for Buildings and Columns, Castings for Engines.

From England: none.

From America: Pig Iron, Pipe Castings, Gray-Iron Castings and Test Bars, Locomotive Cylinders.

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* The German specifications were those prepared by the Deutscher Verband für die Materialprüfungen der Technik. As the final vote upon their acceptance was scheduled for October, the specifications as presented to the Committee were conditioned upon acceptance by final vote. As subsequently developed, that vote was favorable.

The following resolution regarding pig iron was prepared for adoption by the Congress:

Resolution:—"For the purpose of defining more accurately the quality of Pig Iron than is possible by the present method of grading by fracture, the Congress recommends that Sub-Committee Ia be instructed to inquire in the various countries concerned as to how far specifications by analysis may be usefully substituted for the present method of grading by fracture, and that it be authorized to take such steps as it may deem advisable to give effect to this resolution."

This resolution was duly accepted and passed by the Congress.

As to test bars and cast-iron pipe, it was agreed to recommend the following resolutions:

TEST BARS.

Resolution:—"In view of the general acceptance, in principle, of a separately cast "Arbitration Bar" to ascertain the quality of the metal going into iron castings, and the further acceptance of a bar of round section cast on end in dry sand, there remains only to determine the length of bar best calculated to give the most satisfactory technical and commercial results.

"It is therefore recommended that each country interested make a series of tests with bars approximating 1¼ ins. in diameter and cast under standard conditions, the length varying from 6 to 24 ins. between supports, from which this information can be obtained.

"A set of ten bars each for three classes of ordinary gray iron, viz., 1.50, 2.00 and 2.50 per cent. silicon, is suggested, enough bars being cast 26 ins. long and cut up for test purposes. The analyses and records of tests are to be sent to Sub-Committee Ia for their information."

CAST-IRON PIPE.

Resolution:—"That in view of the close approximation of existing specifications for Cast-Iron Pipe in the various countries interested, Sub-Committee Ia be instructed to submit to the Associations in the respective countries copies of the specifications for Cast-Iron Pipe that have been placed before the Congress, with their suggestions as to how unification can best be obtained."

It was not deemed advisable to take up for consideration at this Congress the various German and American Specifications for Castings for Machinery, Buildings, etc.

It should be mentioned that the London Resolutions of Sub-Committee Ia, as given in the Report of Committee A-1, need not be considered as applying to cast iron, since only the specifications for steel were considered at that meeting.

The following work has been done since the Congress:

Pig Iron.—Discussions have been held in England regarding the advisability of bringing their practice into line with that proposed by the above resolutions. In Germany and America the buying and selling of pig iron by analysis is now generally recognized and adopted.

Test Bars.—A paper will be read at this meeting regarding recent tests made in this country as to the proper length for the Arbitration Test Bar. As previously stated, it is proposed that such tests shall be made in the different countries under the supervision of Sub-Committee Ia, so that uniform conclusions may be reached.

Cast-Iron Pipe.—The English engineers and manufacturers are at present discussing the problem of Specifications on the basis of the specifications adopted by the respective Testing Societies in Germany and America.

Regarding the specifications for cast iron in general, it is therefore hoped that before the next Congress in 1912 uniform specifications will have been reached which will justify the course of action adopted by the Committee.

The members of Sub-Committee Ia who were not present at Copenhagen were promptly advised of the work that was done, so that they might know of the proposed use of those specifications that had been already adopted by the National Societies and the steps suggested for the consideration of the Committee by which to accomplish their unification.

Respectfully submitted on behalf of the Committee,

WALTER WOOD,
Chairman.

RICHARD MOLDENKE,
Secretary.

ADDENDUM.

Since the presentation of the above report, Committee Ia of the International Association for Testing Materials has been substituted by two committees, the one on steel exclusively, and the other on cast iron. To the latter committee have been referred the further tests mentioned in the above report, and the specifications connected with cast iron.

November 22, 1910. *W. W.*

REPORT OF COMMITTEE A-5 ON THE CORROSION OF IRON AND STEEL.

The work of the Committee during the past year has consisted in the care and supervision of the wire-fence panels at Pittsburg and the official inspection of the steel panels at Atlantic City. A sufficient time has not yet elapsed to justify a report on the wire tests, so that only the results obtained on the steel plates will be presented at this time.

A brief history of the Atlantic City steel test panels will make the results obtained more interesting to those members of the Society who have not closely followed the work of the Committee. Three years ago the suggestion was made in a paper presented before the Tenth Annual Meeting of this Society,* that the various types of substances used as pigments in protective coatings might exert a stimulative or an inhibitive action on the rate and tendency to corrosion of the underlying metal. It was further suggested on theoretical grounds that slightly soluble chromates should exert a protective action when employed as pigments, by maintaining the surface of the iron in a passive condition in case water and oxygen penetrated the paint film. In view also of the well-known fact that alkalies inhibit while acids stimulate the corrosion of iron, it was suggested that the action of more or less pure pigments on iron in the presence of water should be thoroughly investigated. Two years ago this Committee invited the cooperation of Committee D-1 (then known as Committee E) in the investigation, and a special sub-committee representing the two main committees was appointed.

The methods and results of the water-pigment tests have previously been reported and published,† and need not be given in detail. Briefly, the method consisted in immersing samples of steel in water suspensions of the various pigments and blowing air through the containers for definite periods of time, the corrosion

* "The Corrosion of Iron:" Allerton S. Cushman. *Proceedings*, 1907, Vol. VII, pp. 211–228.

† See Report of Committee E, Appendix II, *Proceedings*, 1909, Vol. IX, p. 203. See also, Bulletin No. 35, Office of Public Roads; also, Bulletins Nos. 7 and 18, Scientific Section, Paint Manufacturers' Association of the United States.

being measured by the loss in weight sustained by the test pieces. About fifty pigments which are in more or less common use for painting steel were purchased in the open market and distributed among a number of the members of the Committee, who agreed to carry out the work. Each investigator worked independently of the others, except that the same general method was followed; the time of exposure to the corroding action, however, varied in the different experiments. When the results were compared and analyzed by the sub-committee, it was felt that the general agreement of the results obtained by the several investigators was striking and merited further and more systematic work. As a result of these tests the sub-committee tentatively divided the pigments into inhibitors, stimulators, and indeterminates. The word "indeterminate" was selected after considerable discussion, because the words "neutral" or "inert" already possess a special meaning as applied to paint technology. The Committee takes this occasion to emphatically state that in adopting this tentative classification, the words "inhibitive" and "stimulative" as used by them up to the present time apply only to the results obtained in the water tests, and the inference that the results obtained have decided which class the pigment will fall into when made into a paint with the usual vehicles and used as a protective coating on iron and steel, is not justified. In order to make this point quite clear, it has been agreed by the Committee to qualify the classification so as to speak of the various materials tested as "water stimulative" or "water inhibitive."

As a result of the preliminary tests, it seemed desirable to the Committee that a systematic investigation of the same pigments should be made under service conditions. The Paint Manufacturers' Association of the United States offered to erect a series of steel panels at Atlantic City and place them under the supervision and control of this Society. The panels were erected in the autumn of 1908 and are now open to the inspection of members. The first official inspection was conducted by the special sub-committee on April 15, 1910. In order to carry out the inspection effectively, a committee of seven inspectors was appointed, each member of which was requested to make an independent inspection and turn in the results to the chairman. The method of examination adopted was as follows: Each plate was given two

TABLE I.—FIRST INSPECTION OF PAINT-TEST S
by Sub-Committee D of C

Fence No.	Panel	Paint.	Examined for	Cushman, *Chairman.*	Chapman.	C
1 Front	1	White lead (Dutch process)	Cor. *	8	9	
			Con. †	3	7	
	2	White lead (quick process)	Cor.	8	9.5	
			Con.	3	8	
	3	Zinc oxide (XX)	Cor.	3	5	
			Con.	2	3	
	4	Sublimed white lead	Cor.	8	9.5	
			Con.	2	8	
	5	Sublimed blue lead	Cor.	9	9.5	
			Con.	1	8	
	6	Lithopone	Cor.	3	6	
			Con.	4	5	
	7	Zinc lead white	Cor.	5	9	
			Con.	5	8	
	9	Orange mineral (American)	Cor.	7	10	
			Con.	6	9	
	10	Red lead	Cor.	6	10	
			Con.	6	9	
	12	Bright red oxide	Cor.	8	10	
			Con.	8	9	
	14	Venetian red	Cor.	6	9.5	
			Con.	6	9	
	15	Metallic brown	Cor.	7	7	
			Con.	5	8	
	16	Natural graphite	Cor.	8	10	
			Con.	7	9.5	
	17	Artificial graphite	Cor.	5	8	
			Con.	6	8	
	19	Lampblack	Cor.	7	8	
			Con.	7	8	
	20	Willow charcoal	Cor.	8	9.5	
			Con.	8	9	
	21	Carbon black (gas)	Cor.	7	9.5	
			Con.	7	9	
	24	Yellow ochre (French)	Cor.	6	7	
			Con.	4	8	
	27	Barytes (natural)	Cor.	2	6	
			Con.	3	7	
	28	Barytes (precipitated)	Cor.	3	5	
			Con.	2	5	
	29	Calcium carbonate (whiting)	Cor.	0	0	
			Con.	0	0	
	30	Calcium carbonate (precipitated)	Cor.	0	0	
			Con.	0	0	
	31	Calcium sulphate (gypsum)	Cor.	1	5	
			Con.	1	4	
	32	China clay (kaolin)	Cor.	3	9.5	
			Con.	2	8	
	33	Asbestine (magnesium silicate)	Cor.	3	9	
			Con.	2	8	
	34	American vermilion (chrome scarlet)	Cor.	10	10	
			Con.	9	9	
	36	Medium chrome yellow	Cor.	6	8	
			Con.	7	7	
	39	Zinc chromate	Cor.	8	10	
			Con.	8	9	
	40	Zinc and barium chromate	Cor.	9	10	
			Con.	8	9	
	41	Chrome green (blue tone)	Cor.	10	10	
			Con.	9	9	
	44	Prussian blue (water stimulative)	Cor.	7	9.5	
			Con.	8	9	
	45	Prussian blue (water inhibitive)	Cor.	8	9	
			Con.	10	9	
	48	Ultramarine blue	Cor.	2	8	
			Con.	0	6	
	49	Zinc and lead chromate	Cor.	9	10	
			Con.	9	9	
	51	Magnetic black oxide	Cor.	9	10	
			Con.	7	9	
	111	Brown (composite paint)	Cor.	5	9	
			Con.	7	9	
	222	Black (composite paint)	Cor.	7	9.5	
			Con.	4	9	
	333	White (composite paint)	Cor.	6	8	
			Con.	6	9	
	444	Green (composite paint)	Cor.	5	8	
			Con.	6	8	
	555	Black (composite paint)	Cor.	8	9.5	
			Con.	9	9	
	666	Brown (composite paint)	Cor.	8	10	
			Con.	8	9	
	777	White (composite paint)	Cor.	7	9.5	
			Con.	4	9	
	888	Green (composite paint)	Cor.	8	10	
			Con.	5	9	
	2000	1 coat zinc chromate, 1 coat iron oxide excluder	Cor.	9	10	
			Con.	6	7	
	3000	1 coat red lead, 1 coat iron oxide excluder	Cor.	7	8	
			Con.	6	7	
	4000	1 coat red lead	Cor.	7	9.5	
			Con.	7	8	
	100	Straight carbon black paint with turps and dryer	Cor.	4	9	
			Con.	9	9	
	90	Straight lamp black paint with turps and dryer	Cor.	6	9.5	
			Con.	8	9	
	5555	Coal tar paint (over red lead)	Cor.	7	6	
			Con.	2	3	
	1000	Chrome resinate in oil, 1 coat	Cor.	4	7	
			Con.	5	5	
	1 (plate)	Boiled linseed oil 3 coats linseed	Cor.	4	7	
			Con.	3	6	

* Cor. signifies corrosion of plate.
† Con. signifies condition of preservative

TEST STEEL PANELS, ATLANTIC CITY, N. J.
e D of Committee D-1.

oman.	Gardner.	Lyon.	Toch.	Voorhees.	P. H. Walker.	Average.	Maximum.	Minimum.
9	9	9	7	9	10	8.7	10	7
7	6	7	5	6	9	6.1	9	3
9.5	9	10	7	9	10	8.9	10	7
8	6	7	6	6	9	6.5	9	3
5	4	5	0	2	2	3.0	5	0
3	5	4	0	5	2	3.0	5	0
9.5	10	10	8	10	10	9.5	10	8
8	9	9	10	7	9	7.7	10	2
9.5	10	10	9	10	10	9.6	10	9
8	9	10	10	6	9	7.5	10	1
6	5	6	5	2	2	4.1	6	2
5	5	6	2	5	5	4.5	6	2
9	8	9	7	8	10	8.0	10	5
8	8	9	8	8	9	7.8	9	5
0	10	10	6	10	10	9.0	10	6
9	9	10	6	9	10	8.4	10	6
0	10	10	6	9	10	8.7	10	6
9	9	9	6	8	9	8.0	9	6
10	9	10	8	10	10	9.3	10	8
9	8	9	9	8	9	8.5	9	8
9.5	5	6	6	9	9	7.2	9.5	5
9	8	6	6	8	7	7.1	9	6
7	6	8	6	5	5	6.3	8	5
8	7	8	6	7	7	6.8	8	5
10	8	10	8	10	10	9.1	10	8
9.5	8	10	6	9	9	8.3	10	6
8	7	9	7	6	8	7.1	9	5
8	8	9	7	7	9	7.7	9	6
8	6	9	7	5	8	7.1	9	5
8	7	9	7	7	9	7.7	9	7
9.5	9	10	8	9	8	8.8	10	8
9	9	9	8	8	9	8.5	9	8
9.5	6	10	8	9	9	8.3	10	6
9	8	10	7	8	9	8.3	10	7
7	5	10	5	5	3	5.8	10	3
8	5	7	5	6	5	5.7	8	4
6	5	8	5	2	2	4.4	8	2
7	6	8	2	6	4	5.1	8	2
5	5	7	5	2	2	4.1	7	2
5	5	6	2	2	6	4.0	6	2
0	0	1	0	0	0	0.1	1	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
5	0	6	1	0	5	2.5	6	0
4	2	6	1	0	5	2.7	6	0
9.5	10	9	5	9	6	7.3	10	3
8	8	8	5	5	6	6.0	8	2
9	10	9	5	8	7	7.3	10	3
8	9	9	5	8	7	6.8	9	2
10	10	10	9	10	5	9.1	10	5
9	10	10	10	8	9	9.3	10	8
8	6	8	5	9	7	7.0	9	5
7	8	8	5	8	8	7.3	8	5
10	10	10	8	10	10	9.4	10	8
9	10	9	10	8	9	9.0	10	8
10	10	10	9	10	10	9.7	10	9
9	10	10	9	8	9	9.0	10	8
10	10	10	9	10	10	9.8	10	9
9	10	10	9	8	9	9.1	10	8
9.5	10	10	8	10	10	9.2	10	7
9	10	9	8	8	10	8.8	10	8
9	10	10	7	10	8	8.8	10	7
9	10	9	7	9	10	9.1	10	7
8	2	7	1	4	4	4.0	8	1
6	2	5	1	4	4	3.1	6	0
10	10	10	8	10	10	9.5	10	8
9	10	9	9	8	9	9.0	10	8
10	9	10	9	10	10	9.5	10	9
9	9	9	9	8	10	8.7	10	7
9	10	9	9	10	8	8.5	10	5
9	10	9	9	8	10	8.8	10	7
9.5	10	9	7	10	9	8.8	10	7
9	9	4	7	6	7	6.5	9	4
8	9	6	5	9	8	7.3	9	5
9	9	8	5	6	7	7.1	9	5
8	9	9	5	9	9	7.7	9	5
8	9	8	5	7	8	7.3	9	5
9.5	8	10	9	10	9	9.1	10	8
9	8	9	9	8	9	8.7	9	8
10	8	10	8	10	9	9.0	10	8
9	8	9	8	8	9	8.4	9	8
9.5	8	10	9	10	10	9.1	10	7
9	8	8	9	7	9	7.7	9	4
10	8	10	10	10	10	9.4	10	8
9	8	9	9	8	10	8.3	10	5
10	10	9	5	10	6	8.4	10	5
7	8	7	10	6	8	7.4	10	6
8	10	10	5	8	6	7.7	10	5
7	7	7	5	6	8	6.5	8	5
9.5	10	10	8	9	6	8.5	10	6
8	8	8	8	6	8	7.5	8	6
9	7	10	7	10	8	7.8	10	4
9	7	10	4	7	10	8.0	10	4
9.5	7	10	9	10	7	8.3	10	6
9	7	10	6	8	9	8.1	10	6
6	0	5	0	8	4	4.3	8	0
3	0	4	0	6	1	2.3	6	0
7	0	5	0	3	2	3.0	7	0
5	0	5	0	3	3	3.0	5	0
7	0	9	0	0	0	2.8	9	0
6	0	8	0	0	0	2.2	8	0

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separate marks graded upon a scale of ten, one mark to signify the condition of the plate as far as effects of corrosion were discernible, and the other to grade as nearly as possible the present condition of the protective coating. In judging condition, various factors were taken into account, such as chalking, checking, cracking, scaling, and color. It was the unanimous opinion of the inspectors that so little difference existed in the duplicate panels on the different steels and fences, that a careful report on one line of panels would answer for all up to the present time. The results of the inspection are presented in Table I, showing the values given by each inspector, as well as the average, maximum, and minimum for each panel.

The original object of these tests was to determine whether the results obtained under service conditions bear any relation to the inhibitive and stimulative effects obtained in the laboratory water tests which have been previously described and published. For the convenience of those members who are interested in a comparison of the results of the two tests, two additional tables are

TABLE II.—ANALYSIS OF AVERAGES. GRADE OF EXCELLENCE FROM 8 TO 10.

(Only resistance to corrosion was considered, and only pigments which were common to both tests are included.)

No.	Pigment.	Average.
34	American vermilion (chrome scarlet)*	9.8
41	Chrome green (blue tone)	9.8
40	Zinc and barium chromate	9.7
5	Sublimed blue lead	9.6
4	Sublimed white lead	9.5
49	Zinc and lead chromate	9.5
39	Zinc chromate	9.4
12	Bright red oxide	9.3
44	Prussian blue (water stimulative)	9.2
16	Natural graphite	9.1
9	Orange mineral (American)	9.0
36	Medium chrome yellow	9.0
2	White lead (quick process)	8.9
20	Willow charcoal	8.8
45	Prussian blue (water inhibitive)	8.8
1	White lead (Dutch process)	8.7
10	Red lead	8.7
7	Zinc lead white	8.0

*Average of six, leaving out W. H. Walker's low value of 5, which was evidently in error. This action was authorized by vote in committee.

appended. Table II gives in order all the simple pigments that attained an average of from eight to ten in the exposure tests on the steel panels. Table III gives in order the pigments which had the highest inhibitive effects in the water test. It is the opinion of the Committee that the panel tests have not progressed far enough

TABLE III.—CHART OF FINDINGS OF MEMBERS OF COMMITTEES D-1 AND A-5.

Loss of Steel in Grams in Tests Carried Out on Pigments to Ascertain Their Value as Rust Inhibitors.

No.	Pigment.	Gardner. No. 1, 20 days.	Cushman. Nos. 1 and 2, 10 days.	P. Walker. No. 2, 74 days.	Cushman. No. 2, 10 days.	W. Walker. No. 1.	Average.
1	Zinc chromate	0.0050	0.0300	0.0094	0.0130	0.0396	0.0194
2	Zinc and barium chromate	0.0153	0.0468	0.0034	0.0140	0.0351	0.0229
3	Zinc and lead chromate	0.0094	0.0277	0.0153	0.0085	0.0620	0.0246
4	Zinc oxide	0.1524	0.0296	0.1002	0.0085	0.0504	0.0682
5	Zinc lead white	0.0842	0.1712	0.0515	0.0856	0.0456	0.0876
6	Barium chromate	0.2333	0.0101	0.0429	0.0094	0.1932	0.0978
7	Ultramarine blue	0.0247	0.3185	0.0137	0.1865	0.0496	0.1186
8	Chrome green (blue tone)	0.0860	0.2269	0.0548	0.1240	0.2246	0.1453
9	Prussian blue (water inhibitive)	0.1438	0.2267	0.0448	0.1150	0.2671	0.1591
10	Lithopone	0.0160	0.3791	0.1274	0.1792	.....	0.1754
11	Willow charcoal	0.1694	0.2795	0.1459	0.1262	0.2110	0.1880
12	Litharge	0.4325	0.1932	0.0309	0.1584	.....	0.2038
13	Dutch process white lead	0.2040	0.2895	0.1781	0.1150	0.2743	0.2122
14	Quick process white lead	0.2120	0.3352	0.1268	0.1848	0.2274	0.2176
15	Calcium sulphate	0.5966	0.2143	0.1759	0.1597	0.2174	0.2328
16	Metallic brown	0.3774	0.2620	0.1983	0.1408	0.1974	0.2352
17	Orange mineral (French)	0.3950	0.2724	0.1495	0.1467	0.2526	0.2432
18	Calcium carbonate (whiting)	0.3828	0.3620	0.1384	0.2380	0.1208	0.2484
19	Sublimed blue lead	0.3177	0.3425	0.1001	0.2365	.....	0.2492
20	Lemon chrome yellow	0.2767	0.4067	0.1365	0.1972	.....	0.2543
21	Orange chrome yellow	0.2826	0.4203	0.1700	0.1907	0.2150	0.2557
22	Medium chrome yellow	0.4090	0.3767	0.1319	0.1763	0.2288	0.2645
23	Chrome green	0.3265	0.3670	0.1348	0.1453	0.3521	0.2651
24	Venetian red	0.2682	0.4756	0.1955	0.2375	0.1564	0.2666
25	Bone black	0.3392	0.3245	0.0921	0.1413	0.4401	0.2674
26	Asbestine	0.2394	0.4025	0.1748	0.2240	0.2405	0.2762
27	Keystone filler	0.3560	0.4651	0.1366	0.3349	0.1481	0.2881
28	Orange mineral (American)	0.4416	0.4336	0.1719	0.2065	0.2315	0.2970
29	Umber	0.1365	0.5961	0.1498	0.3817	0.2403	0.3009
30	China clay	0.3493	0.4770	0.1248	0.2445	0.5212	0.3034
31	Calcium carbonate (precipitated)	0.3574	0.4910	0.1828	0.2625	0.2616	0.3111
32	Red lead	0.3112	0.3555	0.1495	0.1717	0.5707	0.3117
33	Prussian blue (neutral)	0.3584	0.4463	0.1218	0.2415	0.4173	0.3171
34	Indian red	0.3546	0.3739	0.2617	0.1905	0.4334	0.3228
35	American vermilion	0.4328	0.4147	0.2612	0.1877	0.3387	0.3270
36	Sublimed white lead	0.4176	0.5856	0.0982	0.2572	0.3116	0.3300
37	Sienna	0.2876	0.5432	0.2949	0.3085	0.4462	0.3761
38	Naples yellow	0.6482	0.4800	0.1512	0.2347	0.3846	0.3797
39	Prussian blue (water stimulative)	0.5113	0.4559	0.2055	0.2195	0.5202	0.3825
40	Mineral black	0.3050	0.8018	0.2017	0.3529	0.3353	0.3993
41	Barytes	0.4454	0.5883	0.2547	0.2841	0.5636	0.4472
42	Natural graphite	0.4342	0.5437	0.2606	0.3173	0.7165	0.4545
43	Bright red oxide	0.3878	0.7896	0.2920	0.3707	0.4429	0.4566
44	Artificial graphite	0.5262	0.6337	0.3723	0.2789	0.5095	0.4641
45	Ochre	0.4022	0.8408	0.2119	0.4315	.....	0.4716
46	Carbonith white	0.2655	.....	.....	.....	0.7152	0.4904
47	Carbon black	0.5003	0.6955	0.4069	0.3751	0.5716	0.5099
48	Precipitated blanc fixe	0.5247	0.8806	0.3132	0.5085	0.5064	0.5467
49	Lampblack	0.7180	1.3098	0.2838	0.7096	0.6257	0.7294

as yet to justify definite conclusions being drawn. It is not only possible but probable, that in the course of time many of the plates tha are at present in good condition will begin to fail and fall below others which now show slight deterioration. It is at once apparent, however, from an inspection of these tables, that those pigments whose protective value depends upon the principle of chromate inhibition, as well as those which produce basic reactions in water suspensions, have given a good account of themselves on the steel panels. In Table II, out of eighteen pigments common to both series of tests, there are but five exceptions to the above statement, represented by Pigments Nos. 5, 12, 44, 16 and 7.* All these pigments are claimed to be good excluders and do not depend upon solubility in water, and consequently on any inhibitive value, for the protection provided. Beyond calling attention to this point, the Committee prefers to refrain from drawing conclusions at this time from the results of these tests.

The Committee is unanimously of the opinion that up to the present time no differences are discernible in the duplicate protective coatings applied to different types of steel or to surfaces prepared in different ways. As would be expected, however, the panels which faced the ocean and acted to some extent as a wind break to the other lines, show slightly advanced deterioration.

In addition to the single pigments which were common to both series of tests, a number of composite paints were included. These composites were made up in part from water stimulatives and in part from water inhibitives. Both types, however, were to some extent reinforced with other pigments from the indeterminate class. Such results as have been obtained so far can be judged by an inspection of the tables.

It was the consensus of opinion in the Committee that the results of the inspection would be made more thorough by removing the paint films from one set of plates, so that the condition of the underneath surface could be examined. As there are six duplicate panels for all of the single pigments, the Committee felt that this could be afforded, and consequently this action was voted and a sub-committee appointed to carry out the work. The results obtained are now on exhibition at this meeting.

* Pigment No. 7, zinc lead white, might almost be considered a water inhibitor, owing to its content of ZnO (50 per cent.).

The report of the special sub-committee which had direct charge of the preparation, erection and painting of the steel test panels is appended to this report. The report gives information necessary to the proper understanding of all the details of the tests, and is, in the main, self-explanatory. One or two points, however, require further explanation. In some cases the general method adopted for making up the paints with a standard quantity of oil did not yield a proper painting consistency, which therefore necessitated the addition of a certain amount of turpentine. Special difficulties were encountered in the application of some of the black pigments, and in order to reduce these to a proper consistency they were used in combination with definite amounts of barytes. This was unfortunate, as it may completely destroy the comparative value of the tests as far as these black pigments are concerned. In view of the fact that none of the straight barytes panels, Nos. 27 and 28, escaped deterioration in the tests, it was manifestly unfair to the black pigments to mix them with this material. The results obtained on these particular panels should therefore be interpreted as applying only to the specific mixtures employed.

Respectfully submitted on behalf of the Committee,

A. S. CUSHMAN,
Chairman.

W. H. WALKER,
Secretary.

Appendix.

REPORT OF JOINT SUB-COMMITTEE IN CHARGE OF ERECTION AND PAINTING OF STEEL TEST PANELS AT ATLANTIC CITY.

All the pigments enumerated in Table IV were ground in quantities of the weight shown, in two thirds of a gallon, by measure, of raw linseed oil, and one third of a gallon of boiled linseed oil, without regard to consistency, as arranged. The resulting material was put up in one-quart friction-top cans, the covers of which were stamped with the letter "P" and a number, as per key given. The labels read "Pigment No. 1," and so on.

Preparation of Formulas.—The preparation of the formulas for the paints to be used in the field test required the determination of the specific gravity of the various pigments, and when this was accomplished a definite formula for the grinding was decided upon, so that the same amount by volume of each pigment would be used in the same quantity of oil, viz., specific gravity of pigment x 3 = pounds of pigment to gallon of oil. It was decided to grind these pigments separately, in a mixture of two-thirds raw and one-third boiled linseed oil, no drier being included because of the unknown factor which would be introduced by the lead content of such drier.

Besides the pigments ground separately in oil, a series of composite paints was made. These paints were made up in part mainly from the water inhibitive and in part from the water stimulative types of pigments. The composition of these special paints is given in Table V.

Preparation of Plates.—Several hundred plates were obtained for the test and one half the number were pickled in sulphuric acid, then neutralized with soda ash, thoroughly washed, and preserved from future oxidation in dry lime until needed for the test. The removal of the mill scale was complete in the case of the pickled plates and a perfectly clean, neutral surface was obtained upon which to apply the paints.

Painting of Plates.—The painting of the plates was done under cover in a temporary building erected for the purpose. This

TABLE IV.—TABLE OF INFORMATION REGARDING PAINTS.

Pigment No.	Name of Pigment.	Wt. of Pigment per Gal. of Oil, lbs.	Sp. Gr. of Paint as Rec'd.	Grams of Paint to Panel at 900 sq. in. spreading rate.
1	Dutch process white lead	20.49	2.45	61.0
2	Quick process white lead	20.34	2.47	62.0
3	Zinc oxide XX	16.68	2.12	*59.0
4	Sublimed white lead	19.17	2.36	59.0
5	Sublimed blue lead	19.17	2.42	61.0
6	Lithopone	12.78	1.80	45.3
7	Zinc lead white	13.26	1.96	49.4
9	Orange mineral (American)	26.91	2.97	74.7
10	Red lead	26.10	2.93	73.6
12	Bright red oxide	15.78	2.05	†60.0
14	Venetian red	9.30	1.52	38.0
15	Metallic brown	9.51	1.50	37.7
16	Natural graphite	7.80	1.37	34.4
17	Artificial graphite	6.63	1.22	30.8
19	Lampblack Natural barytes	1.82 8.92	1.60	40.2
20	Willow charcoal	4.47	1.08	27.0
21	Gas carbon black Natural barytes	1.39 10.03	1.67	‡50.7
24	French yellow ochre	8.82	1.46	37.0
27	Barytes (natural)	13.38	1.83	46.0
28	Barytes (precipitated)	12.69	1.84	46.0
29	Calcium carbonate (whiting)	8.22	1.37	34.5
30	Calcium carbonate (precipitated)	7.68	1.35	34.0
31	Calcium sulphate (gypsum)	6.99	1.25	31.4
32	China clay (kaolin)	8.01	1.34	34.0
33	Asbestine (silicate of magnesium)	8.25	1.38	34.7
34	American vermilion (chrome scarlet)	20.49	....	64.5
36	Medium chrome yellow	17.64	....	§67.1
39	Zinc chromate	10.71	1.57	39.2
40	Zinc and barium chromate	10.35	1.58	40.0
41	Chrome green (blue tone)	13.32	1.94	49.0
44	Prussian blue (water stimulative)	5.88	....	30.0
45	Prussian blue (water inhibitive)	5.79	....	‖34.5
48	Ultramarine blue	7.20	1.29	32.5
49	Zinc and lead chromate	14.28	1.92	48.3
51	Magnetic black oxide	15.00	1.92	48.3
	COMPOSITE PAINTS.			
111	Brown — Made from pigments that were inhibitive in the water test	10.82	1.30	32.7
222	Black — Made from pigments that were inhibitive in the water test	10.86	1.30	32.8
333	White — Made from pigments that were inhibitive in the water test	14.52	1.744	43.8
444	Green — Made from pigments that were inhibitive in the water test	12.77	1.53	38.6
555	Black — Made from pigments that were stimulative in the water test	9.37	1.125	28.0
666	Brown — Made from pigments that were stimulative in the water test	11.74	1.41	35.5
777	White — Made from pigments that were stimulative in the water test	14.55	1.75	44.0
888	Green — Made from pigments that were stimulative in the water test	14.57	1.75	44.0

* 50.5+8.5. Thick paste, requiring 170 grams turpentine to thin 1,000 grams to working consistency, thus raising the amount per panel to 59 grams.

† 51.5+8.5. 1,000 grams paste required 166 grams turpentine.

‡ 42+8.72. 1,000 grams paste required 218 grams turpentine.

§ 56+11.1. 1,500 grams paste required 299 grams turpentine.

‖ 29.5+5.0. 1,000 grams paste required 163 grams turpentine.

TABLE V.—COMPOSITION OF SPECIAL FORMULAS.

Pigment Formula.	Ingredients.	Paint Formula.	Pigment Formula.	Ingredients.	Paint Formula.
	No. 111.			No. 222.	
60	Burnt umber.....	22.50	30	Bone black.	13.72
20	Zinc and Barium chromates.....	7.50	2	Prussian blue.....	0.92
			10	XX zinc.....	4.57
20	Zinc lead.....	7.50	50	Silex.....	22.86
	Japan.....	3.40	8	Calcium carbonate..	3.66
	Raw oil.....	59.10		Japan.....	8.33
				Raw oil.....	45.94
	No. 333.			No. 444.	
35	Zinc oxide.....	20.90	60	XX zinc.....	32.47
45	Zinc lead.....	26.87	15	Zinc chromate.....	8.30
5	Calcium carbonate..	2.98	3	Prussian blue I...	1.44
15	Silex.....	8.95	2	Calcium carbonate..	1.08
	Japan.....	1.56	20	Silex.....	10.83
	Raw oil.....	38.74		Japan.....	2.22
				Raw oil.....	43.66
	No. 555.			No. 666.	
40	Lamp black.....	8.18	50	Red oxide, 62 a	22.94
40	Natural graphite....	8.18	5	Carbon black.....	2.35
20	Barytes.....	4.09	35	Barytes.....	15.30
	Japan.....	8.33	10	Med. chrome yellow	5.88
	Raw oil.....	71.22		Japan.....	3.20
				Raw oil.....	50.33
	No. 777.			No. 888.	
60	Sublimed white lead.	44.80	5	Chinese blue S.....	4.32
20	Blanc fixé.....	7.46	35	Lemon chro. yellow.	18.94
20	Gypsum.....	7.46	20	Sublimed white lead.	16.23
	Japan.....	1.60	40	Barytes.....	21.35
	Raw oil.....	38.68		Japan.....	2.35
				Raw oil.....	38.51

was necessary in order to have uniform conditions for the application of each formula. A definite spreading rate of 900 sq. ft. to the gallon was used on the paints applied to the cleaned plates, while the paint applied to the black plates—i. e., those not pickled, and having the ordinary black mill scale—had no definite spreading rate. The paint was applied by the painters representing the Commit ee and the Master Painters' Association, under the constant supervision of the Director of Tests. Three-coat work was used throughout on the cleaned plates upon which the original fifty-one pigments were applied; but in some cases, on the black plates, where the special formulas were applied, two-coat work was used.

Details of Application.—After the specific gravity of the paint had been taken and the amount necessary for the application to each panel had been determined according to the spreading rate, a quart of paint was placed in a half-gallon enameled cup, and stirred well to bring the mixture to thorough incorporation. A brush was thoroughly worked into the paint, and pot and all were placed upon the balance and the weight taken in grams, using the metric system throughout the test. The pot was then handed to the painter, who applied the paint to one plate. The number of grams applied to each panel was deducted from the counterbalance, and when the pot, paint and brush exactly balanced, the panel was cross-brushed and laid out. The final weighing was then made to see that the counterbalance was maintained. The plates during the work were set upon a frame resting upon a bench, room being allowed beneath the plate for the painter to place his hands when lifting it, after the brushing had been finished. The plate was then taken from the bench and slid into a specially prepared rack, so that the paint would dry in a horizontal position. Racks for several hundred of these plates were built and used during the test.

A sufficient length of time between the coats was allowed for the thorough drying of each pigment. Extreme care was used in painting the edges of the plates, for the reason that corrosion generally starts at this point of attack. Each pigment was applied in duplicate to each class of steel, so that when set upon the fence, they could be placed in both an eastern and western exposure.

No reductions were made to any of the paints applied, except in one or two cases (see report), where the viscosity of the paint was so great that the possibility of brushing was precluded. A small amount of turpentine was added in these cases and the amount of paint to be applied to the panel proportionately increased, so that when the turpentine evaporated, the amount of paint originally intended would be left upon the plate.

Fences.—The fences upon which the steel plates were fastened after the painting are three in number, and each one is 125 ft. long and 5 ft. high. They are built of 4 by 4-in. yellow-pine studding, the posts being set 8 ft. apart, and strongly counterbraced underneath the surface of the ground with 2 by 4-in. pieces. A strip of 2-in. batton is provided along the lower beam on either side of

each fence, as a resting place for the plates. The plates rest on two small pieces of rawhide fastened 18 ins. apart on the battons, thus being raised a sufficient distance from the bat:on to prevent the accumulation of water at the bottom of the plates. The plates rest and back against the beams at top and bottom, and are fastened to these beams by metal buttons screwed into the wood between and lapping over an equal distance on two plates. Insulation of the buttons was obtained by interpos ng rubber strips between the plates and the button. The buttons were enameled and the screw heads painted and subsequently plugged with putty. This method of fastening the plates obv ates the bad practice of drilling screw-holes through the plates, which invariably starts a place of corrosion. Each plate has, lettered upon its lower left-hand corner, the number of the paint or pigment with which it is painted, and a numeral to show the class of steel used. Below each plate, in order to secure permanent identification, these same numbers are stamped in the wooden fence.

BRIEF DESCRIPTION OF PIGMENTS USED IN TEST.

1. *Dutch Process White Lead.*—Made by the well-known old Dutch process of corrosion.

2. *Quick Process White Lead.*—Made by the quick process.

3. *Zinc Oxide XX.*—Made from sublimation of New Jersey zinc ores.

4. *Sublimed White Lead.*—Sublimed from Missouri lead ores.

5. *Sublimed Blue Lead.*—Made by burning coarsely broken galena mixed in a furnace with bituminous coal. The fumes arising from this complex mixture are streaked in appearance, white, blue and black. They are drawn from the furnace by suction fans, purified, and collected by suction in a bag room. The material varies considerably in composition, but its working properties are about constant. Its analysis will average about as follows:

Lead sulphate	50	per cent.
Lead oxide	35	"
Lead sulphide	5	"
Lead sulphite	5	"
Zinc oxide	2	"
Carbon	3	"

Its color is due to the carbon and lead sulphide.

6. *Lithopone.*—Manufactured by the double decomposition of zinc sulphate and barium sulphide, the resulting product being filter-pressed and furnaced, after which it is disintegrated while in its heated condition by plunging into water, where it is thoroughly washed and again filter-pressed. It is then dried and ground.

7. *Zinc Lead White.*—Analysis:

Lead sulphate	52.7 per cent.
Zinc oxide	47.2 "

Made by sublimation of sphalerite and galena in the proper proportion, the fumes of which are oxidized and collected in bags.

9. *Orange Mineral (American).*—Made from white lead by the usual method.

10. *Red Lead.*—Made by oxidizing litharge in reverberatory furnaces.

12. *Bright Red Oxide.*—Ninety-eight per cent. oxide of iron (copperas red).

14. *Venetian Red.*—Made by calcining a mixture of copperas and terra alba.

15. *Metallic Brown.*—Made by roasting ore mined in Carbon County, Pennsylvania, for 72 hours at a cherry-red heat, thus changing the iron from the carbonate to the sesquioxide. After the ore is roasted, it is simply ground and is then ready for mixing. Impurities consist of silica and alumina. Analysis of this product runs approximately:

Iron	45 per cent.
Silica (SiO_2)	45 "
Alumina (Al_2O_3)	10 "

16. *Natural Graphite.*

17. *Artificial Graphite.*—Ninety per cent. pure carbon. The ash contains carbide of silicon, a small percentage of silica, iron and aluminum.

19. *Lampblack.*—Ninety-nine per cent. pure carbon, one per cent. ash and volatile matter. Passed United States Government specifications. Made from creosote and refuse oils.

20. *Willow Charcoal.*—From calcination of willow branches. Contains trace of potash.

21. *Carbon Black.*—From combustion of natural gas. Approximates 99 per cent. carbon.

24. *Yellow Ochre.*—Hydrated silicate of iron and alumina.

27. *Barytes.*—Best grade of thoroughly washed, floated barytes. Analysis:

Barium sulphate	99.66 per cent.
Oxide of iron	0.01 "
Lime	0.02 "
Silica	0.22 "
Moisture	0.09 "
Magnesia	Trace
Sulphuric acid free	Trace

28. *Precipitated Blanc Fixé.*—Made by the precipitation of barium chloride and sodium sulphate. May contain traces of sodium sulphate.

29. *Calcium Carbonate (whiting).*

30. *Precipitated Calcium Carbonate.*—Made by the precipitation of calcium chloride and sodium carbonate. May contain trace of alkali.

31. *Calcium Sulphate.*—Natural.

32. *China Clay.*

33. *Asbestine.*—Silicate of magnesium.

34. *American Vermilion.*—Made by boiling white lead and chromate of soda and adding a small quantity of sulphuric acid in order to brighten the shade. This color consists of basic chromate of lead in large crystallized form. It is liable to contain free chromates, small quantities of white lead and sulphate of lead; also small quantities of sulphate of soda.

36. *Medium Chrome Yellow.*—This is pure neutral chromate of lead made from nitrate of lead and chromate of soda. It is practically free from impurities and contains only very minute traces of lead salts and nitrate of soda.

39. *Zinc Chromate.*—This is manufactured from a zinc salt and bichromate of potash. Owing to its solubility, it is impossible to wash perfectly, and it contains, therefore, usually a considerable amount of soluble matter, sulphate of potash, chromates, and zinc oxide.

40. *Zinc and Barium Chromate.*—This was made by precipitating a mixture of zinc chloride and barium chloride with

chromate of soda. The remarks under No. 39 apply here also. The product contains considerable soluble matter, consisting of zinc chloride, barium chloride, sodium chloride and chromates.

41. *Chrome Green, Blue Shade.*—This was made from nitrate of lead, bichromate of soda, and oil of vitriol, precipitated on white lead and Chinese blue. Beside chromate of lead, the resultant product contains sulphate of lead, Chinese blue, and white lead. It is liable to contain nitrate of lead salts and nitrate of soda.

44. *Prussian Blue, Water Stimulative.*—This is a Chinese blue, made from prussiate of potash and copperas. It was oxidized with chloride of lime. The resulting product contains small quantities of chlorides.

45. *Prussian Blue, Water Inhibitive.*—This is a Prussian blue made from prussiate of potash and copperas. It was oxidized with bichromate of potash. It contains a certain amount of chromates, to which its water inhibitive qualities are probably due.

48. *Ultramarine Blue.*—Made from silica, china clay, soda ash, and sulphur, combined chemically by burning in pots in furnaces, the resulting product being ground, bolted, etc. Analysis of this product shows the presence of the above compounds.

49. *Zinc and Lead Chromate.*—This was made from zinc and lead acetates and chromate of soda. It contains small quantities of zinc and lead acetates and of chromates, also of acetate of soda.

51. *Magnetic Oxide of Iron.*—Not, properly speaking, a magnetic oxide. Made by neutralizing acid ferrous sulphate liquors with an alkali and blowing air through.

Respectfully submitted on behalf of the Joint Committee,

H. A. GARDNER,
Chairman.

JOINT DISCUSSION OF REPORTS OF COMMITTEES A-5 AND D-1.

Mr. A. S. Cushman.—I am sure that every one who has inspected the Atlantic City steel test plates even so short a time ago as April 15, has found that a great change has taken place upon them in these last two months, so that if the official inspection were to be made to-day I am sure that there would be certain changes necessary in the grading as given in this official report. If the life of a paint coating could be represented graphically, it would show a rather straight curve for a certain time, which would then suddenly drop off. In other words, when failure of a coating is once discernible it goes on rapidly to destruction. **Mr. Cushman**

The President.—It should be a source of very great gratification to the Society to find that this excellent and important work is being done with such thoroughness. The importance of it is really very hard to grasp. Considering the enormous amount of exposed iron surfaces throughout the world, the matter of properly protecting the same is obviously one of very great moment. That it should be taken up so systematically, so thoroughly, and so laboriously by our sub-committees should be a matter of great pride to us, and of gratitude to the sub-committees which have done this work. **The President.**

Mr. C. M. Chapman.—I should like to ask if the Committee is including in its report any statement of a difference between plates which were pickled and those which were black. **Mr. Chapman.**

Mr. Cushman.—The Committee is unanimously agreed that so far as our knowledge goes at the present time, there is no difference discernible in any of the duplicate plates, whether they are different steels or whether they are differently prepared surfaces; but you will please note, *up to the present time.* **Mr. Cushman**

Mr. S. S. Voorhees.—In that connection I would say that in the report made by Mr. Aiken on the Havre de Grace bridge, it is noted that paints on the specially prepared plates are apparently not in such good condition as on the bridge proper. These plates were pickled. If this superiority is maintained on continued **Mr Voorhees.**

Mr. Voorhees. exposure, the treatment of the plates prior to painting will require further investigation. In talking to Mr. Gibbs of the Pennsylvania Railroad last evening, he told me that it is no longer the practice to pickle the steel plates used in steel-car construction; they have given that up, and are sand-blasting instead.

Mr. Chapman. MR. CHAPMAN.—I should like to emphasize one point. Our experience in testing paints has indicated that the black scale which is tight on the plate is a pretty good protector in itself. If one can remove the loose scale and leave the tight scale, the result will be increased protection against rust.

Mr. Tassin. MR. WIRT TASSIN.—I have found in every case that the pickled plate which had not been baked but simply neutralized by putting it in limewater presented anomalies which were not characteristic of the pickled plate that had been baked. I found that those plates which had not been pickled, or which had been simply pickled a little, not only had a very much better surface for holding pigments, but seemed not to possess anomalies characteristic of the pickled plates which had not been baked.

Mr. Cushman. MR. CUSHMAN.—Does not baking the plate put a skin of blue oxide on the surface again?

Mr. Tassin. MR. TASSIN.—Always.

Mr. Cushman. MR. CUSHMAN.—Then if you bake you are really making an oxidized surface, only you are making a more even coating of the blue oxide? In my opinion the hydrogen which produces blistering of a paint coating is not that which is absorbed by the iron during pickling, but that which results from the electrolysis which is a concomitant of the action which goes on whenever and wherever iron rusts.

Mr. Tassin. MR. TASSIN.—We know that the pickling itself has an action on the physical properties of the steel; in other words, there is a certain amount of hydrogen occluded in the steel which must be given off at some period of time. I assume that that also has something to do with the continuity of the film; that is, this hydrogen, passing out through the pores, would eventually get to the surface, and of course baking drives that out immediately.

Mr. Walker. MR. P. H. WALKER.—I should like to call the attention of the members to a mistake which I made in the inspection of the fence referred to by Mr. Cushman. The mistake was in the marking of the plate painted with vermilion. My original mark

was No. 5, and when I saw I was absolutely in the minority, I assumed that it was perhaps a clerical error. I went to the plate yesterday and made another careful inspection. When I first looked at it I came to the conclusion that I was not in error, and as well as I could tell with the naked eye, my original mark would have stood. I then examined this plate carefully with a lens. It has on it a number of spots that looked to me like rust, and even with the lens it still had that appearance. I was very much puzzled to find how the other men had missed it. It then occurred to me to wash the plate, whereupon I found that the discoloration was entirely on the top of the paint film. I do not know what the material is, unless possibly it is coal dust. If I were required to grade that paint again, I should grade it No. 10. **Mr. Walker.**

A MEMBER.—I should like to ask how those plates were cleaned. **A Member.**

MR. H. A. GARDNER.—Do you refer to the pickling of the plates, or the cleaning off of the paint? The plates were all removed from the fence and taken in the presence of the Inspection Committee to a small shed. After one-half the painted surface had been covered with a board, the remaining surface was cleaned with a paint-remover made of acetone, benzol and wax. This was brushed on the surface, and after ten minutes the paint was loosened to such an extent that it could easily be removed with a 3-in. scraping knife. The films came off in long strips about 3 ins. wide, leaving the bare surface of the metal, which in some cases was corroded and in other cases was perfectly clean. In some instances the strips of paint when removed had on their surfaces very large areas of corrosion which adhered to the film itself. In one case (basic carbonate, white lead) I took a photograph of the film with the adhering rust, which was very thick. On some plates the corrosion was very thick, and on others there was no corrosion at all. **Mr. Gardner.**

MR. CUSHMAN.—I think Mr. Gardner should have added, for the information of the members, that as soon as the paint films were removed from half the panels the plates were quickly dried, and then given a coat of thin shellac dissolved in alcohol. This was done to preserve the plates for the time being so that no superficial rust would appear on those surfaces until the members present had an opportunity to complete their inspection. It is **Mr. Cushman.**

Mr. Cushman. not to be supposed that a single coat of shellac will preserve the surfaces indefinitely.

Mr. Carpenter. MR. A. W. CARPENTER.—I have had an opportunity, in the last four or five years, to make quite a few tests with paint coatings on steel plates, and one thing which impressed me when looking at these plates on the fence was that they were painted with three coats in apparently the most excellent manner, and yet, after an exposure of only about twenty months, these coats are in many cases going to pieces, or showing defects. In the atmosphere of New York City such coatings, I venture to say, would show up better with even two or three times that length of exposure. I do not know whether the point has been brought out before that the atmosphere of Atlantic City is evidently an unusual one. I think that is a point which possibly might and should be taken into account in judging the results of these tests. The results may not be applicable to ninety-nine per cent. of the territory of the United States.

Mr. Voorhees. MR. VOORHEES.—I think that point was considered when making a comparison of the plates at the Havre de Grace bridge, which have been up five years, with the plates here, which have been up only about a year and a half. In many cases the plates at Havre de Grace are in better condition than the plates here.

Mr. Cushman. MR. CUSHMAN.—I should like to say in this connection, that although it is true that Atlantic City presents accelerative conditions, it was just for that very reason that Atlantic City was selected as the place to erect the test panels. Some of us are getting old and we might die before we learn anything. Then again, I wish to make the point that in many cases things look well on the outside but—it is the old whited sepulchre over again—are rotten underneath. I understand that in these tests, there is no intention or desire on the part of the Committee—and in voicing the feeling of the Committee I believe I am speaking for the entire American Society for Testing Materials—to make any invidious comparisons between different materials for paints to be applied to iron and steel. We are endeavoring to do something better than that; we are studying principles. We want to ascertain if it is true that a paint coating may look quite well for a number of years, yet allow corrosion to start underneath, so that the time soon comes when it rapidly fails and goes to pieces. We want to see if it is

possible to so design our paint, that if it is properly applied it will not only present a good appearance on the outside, but will also preserve the surface of the steel that it covers. If we can do this—I do not say that we have already accomplished this, although we have in my personal opinion made several steps in the right direction—we will have achieved something from these tests that will repay all of the arduous work that has been done by those who have put their time and thought into it. **Mr. Cushman.**

MR. GARDNER.—On several of the paints I noticed small blisters appearing, and at first I thought these blisters might have been caused by occluded hydrogen in the metal, which had developed during the pickling process; but I concluded later that these blisters were due to another cause, as they all appeared on panels which were painted with pigments of the water stimulative type. I reasoned that the moisture going through the paint film would act on the iron in the presence of oxygen and cause corrosion, and the hydrogen which was developed would be de-polarized by the painted surface, and then the de-polarized hydrogen would form the little nodules or blisters which split open and caused active corrosion and pitting. I noticed in every case where a water inhibitive pigment was used that a perfect condition of the film was shown after an exposure of twenty months. **Mr. Gardner.**

REPORT OF COMMITTEE A-8 ON STANDARD SPECIFICATIONS FOR COLD-DRAWN STEEL.

As briefly outlined in the report of last year, the Committee has undertaken a series of tests with special reference to the class of material which we have tentatively described as "standard automatic screw stock." In pursuance of an agreement made at a meeting of the Committee held at the last annual meeting of the Society, in 1909, the various consumers represented on the Committee placed orders with each of the producers for cold-drawn steel for automatic screw machine work, for test purposes. The material was to represent the various types proposed for this grade of service.

This material, making a total of about twenty tons, was made up especially by the producers in accordance with the size requirements, etc., of the various consumers, and thorough and systematic tests have been made with this material. While the data obtained from these tests have not as yet been entirely collected and tabulated, results of very considerable value are available, and the Committee confidently expects to arrive at some definite conclusions in regard to this subject before the next annual meeting.

The tests include careful chemical tests, physical tests, tests for machining quality under various conditions and machining speeds, and a complete record of tools used, pieces made, etc., with a view of arriving at a specification for the best commercial grade of steel for the purpose indicated.

The Committee will greatly appreciate any suggestions or data which any of the members of the Society may have to offer in connection with this subject, with a view of taking into account all the possible conditions governing specifications for this class of material.

Respectfully submitted on behalf of the Committee,

C. E. SKINNER,
Chairman.

REPORT OF COMMITTEE A-10 ON STANDARD SPECIFICATIONS FOR STAYBOLT IRON.

At the Tenth Annual Meeting of the Society, held in 1907, your Committee reported proposed Standard Specifications for Staybolt Iron, which were referred back to the Committee for further consideration. The proposed Standard Specifications for Staybolt Iron appended to the present report are the same as those above referred to, printed in the Proceedings, 1907, Volume VII, pages 157-158, except in respect to the following features:

1. The addition of the following clause to the first sentence under "Process of Manufacture:"

> "the basis of which must be pig metal and entirely free from any admixture of steel."

2. The omission of the following matter:

> "The pile must be made up of a central core composed of bars from ½ in. to 1 in. square and be covered on all four sides with an envelope ⅝ in. thick, as per sketch.
>
> "This pile must be rolled to a billet, allowed to cool, again heated, and then rolled into bars of the required dimensions."

3. The substitution of a "Nick and Break Test" for the "Threading Test."

The Committee respectfully recommends the adoption of the proposed standard specifications in their revised form as appended to this report, and that the Committee, having completed its work, be discharged.

Respectfully submitted on behalf of the Committee,

H. V. WILLE,
Chairman.

NOTE.—The Specifications for Staybolt Iron were adopted by letter ballot of the Society on September 1, 1910, and follow this report.—ED.

AMERICAN SOCIETY FOR TESTING MATERIALS

PHILADELPHIA, PA., U. S. A.

AFFILIATED WITH THE

INTERNATIONAL ASSOCIATION FOR TESTING MATERIALS.

STANDARD SPECIFICATIONS FOR STAYBOLT IRON.

ADOPTED SEPTEMBER 1, 1910.

PROCESS OF MANUFACTURE.

All staybolt iron must be hammered or rolled from a bloom or a box-pile having a cross-sectional area of at least 45 sq. ins., and not less than 18 ins. long, the basis of which must be pig metal and entirely free from any admixture of steel.

PHYSICAL TESTS.

(*a*) *Tensile Strength.*—Not less than 48,000 lbs. per sq. in.

(*b*) *Elongation.*—Not less than 28 per cent. in 8 ins.

(*c*) *Reduction of Area.*—Not less than 45 per cent.

(*d*) *Double Bending Test.*—Close in both directions without flaws.

(*e*) *Nick and Break Test.*—A bar, nicked all around to a depth not less than 8 per cent. and not more than 16 per cent. of the diameter of the bar, and broken, shall show a clean fiber entirely free from crystallization.

(*f*) *Vibration Test.*—The test bar shall stand a minimum of 6,000 revolutions when subjected to the following vibratory test:

A threaded specimen, fixed at one end, has the other end moved in a circular path while stressed with a tensile load of 4,000 lbs. The circle described shall have a radius of $\frac{3}{32}$ in. at a point 8 ins. from the fixed end of the specimen.

INSPECTION.

(*a*) The iron must be smoothly rolled and free from slivers, depressions, seams, crop ends and evidences of being burnt.

(*b*) It must be truly round within 0.01 in., and must not be more than 0.005 in. above, or more than 0.01 in. below specified sizes.

SELECTION OF SAMPLES FOR TEST.

The bars will be sorted into lots of 100 bars each and two bars will be selected at random from each pile. Failure of either of these bars to meet any of the above specifications will be cause for rejection of the lot which the tests represent.

REPORT OF COMMITTEE C-3 ON STANDARD SPECIFICATIONS FOR PAVING AND BUILDING BRICK.

The Committee has held two meetings during the year. It has considered problems in connection with standard paving-brick tests, and questions relative to the tentative specifications for building brick presented to the Society last year.

Until recently, the National Brick Manufacturers' rattler test has been quite generally used for determining the quality of paving brick, although the results of this test have not been shown to have a definite relation to the results of service. With the object of securing further information, your Committee has arranged for an investigation as outlined below. The National Paving Brick Manufacturers have agreed to supply over 2,100 samples of each of the different kinds of brick. These samples are to be forwarded to six different laboratories and submitted to the following tests:

(*a*) The Brick Manufacturers' rattler test is to be made at the Ohio State University, under the direction of Professor Orton; at the University of Illinois, under the direction of Professor Talbot; at Indianapolis, by Mr. Blair, for the National Paving Brick Manufacturers' Association; and at the City Testing Laboratory of St. Louis, by Mr. Schuyler.

(*b*) Professor Talbot and Mr. Schuyler will supplement these with tests by the Talbot-Jones rattler.

(*c*) Freezing, absorption, and porosity tests will be made by the Bureau of Standards.

(*d*) Air sand-blast, water sand-blast, and impact tests will be made by the Office of Public Roads.

After a careful consideration of the proposed specifications for building brick tentatively submitted to the Society last year, your Committee has decided to secure further data before recommending that they be submitted to the Society for adoption by

letter ballot. The Committee is considering a cooperative plan of investigation to secure this information, and it is hoped that substantial results may be obtained for presentation to the Society at its next meeting.

Respectfully submitted on behalf of the Committee,

L. W. PAGE,
Chairman.

E. W. LAZELL,
Secretary.

DISCUSSION.

Mr. Howard. MR. J. W. HOWARD.—I understand from the report that a series of examinations of paving brick are about to be made, but that no recommendations are made in regard to tests of paving brick. Am I correct?

Mr. Page. MR. L. W. PAGE.—Yes, sir.

Mr. Howard. MR. HOWARD.—That being the case, I will not speak of the report, but I should like to say something about paving brick. I have tested in past years brick of about 180 different makes from different parts of the United States and the test which needs modification, in my opinion, is the abrasion or rattler test. The standard rattler is now 20 ins. long inside, 28 ins. in diameter, and has 14 facets on the sides with $\frac{3}{16}$-in. spaces between the staves. The rattler makes 30 revolutions per minute for one hour; the charge of bricks is 1,000 cu. ins., which requires about nine of the larger bricks or twelve of the smaller ones. The abrading material is cast shot: at present, 225 lbs. of small cubic shot and 75 lbs. of larger parallelopipedons. The small shot have square edges, and during the progress of the test the first bricks tested with them abrade very severely. Later the corners of the shot become rounded and cause less abrasion of the bricks. It has become necessary to change those shot and now they are to be balls. The small balls are to weigh about 0.9 lb. apiece. The balls are run down through an inclined iron plate with standard holes; the small or worn shot fall through the holes and are thus quickly sorted out. Old city records of brick tests, representing millions of dollars of pavements and much experience, can be converted to the better new standards by established factors or tables.

The real need of tests lies in the fact that brick manufacturers try to sell by "brand" and not by quality. Of the 180 brands of brick with which I am familiar, only about 35 are suitable for durable pavements; and out of these 35, there may be 12 or 14 excellent grades which will stand heavy traffic and wear. There are so many manufacturers who make poor brick that, notwith-

standing the efforts of others, it has been found impossible to establish all tests needed, or to establish a criterion or numerical measure of excellence for any test. It is seen therefore how important it is that this Committee should establish standard tests for paving brick. Engineers met in Chicago this year, representing 44 cities—a small number of the 997 cities of the United States; but notwithstanding opposition in some quarters, that convention made progress in pavement specifications. What was done was only suggestive, to be reported on more fully a year or so later. At that convention specifications for the laying of bricks, the grouting of joints, and details of construction were suggested, but not enough attention was given to testing methods and no criterion or standard of quality for any tests was proposed. This affects an expenditure of about $14,000,000 a year for brick pavements. **Mr. Howard.**

MR. W. H. FULWEILER.—I can find no reference in the report to the crushing and cross-breaking tests that have sometimes been made; from which I infer that the Committee considers that those tests are discredited, and that the necessary information may be obtained better in other ways. **Mr. Fulweiler.**

MR. PAGE.—I cannot speak for the whole Committee, but I think it is the consensus of opinion that the cross-breaking and compression tests are not essential in paving brick. I have never seen a case where a brick failed under compression. I think there is little need for a cross-breaking test if the brick are properly laid and properly grouted. We want to give immediate consideration to the matter of the rattler tests; and in this investigation, as the report stated, we use not only the test that is used by the National Brick Manufacturers, but also the Talbot-Jones rattler, in which the bricks are strapped in place. We are also going to use round shot in both rattlers. The sand and air blasting is purely experimental work. If we find that the results of these much quicker tests parallel those of the rattler tests, much time will be saved. With building brick we included last year the cross-breaking and compression tests. **Mr. Page.**

MR. HOWARD.—The standard paving-brick tests which we use in practical work to fully pre-determine the weathering and wearing qualities of paving bricks, are the abrasion or rattler test, the cross-breaking or modulus-of-rupture test, the water-absorp- **Mr. Howard.**

Mr. Howard. tion test, and tests for density or specific gravity, hardness, and crushing. These are all necessary. The Talbot-Jones rattler, which is seldom used, is one in which the bricks are clamped around the inside and the balls allowed to roll upon them. It requires a great deal of time to prepare. To replace the standard rattlers all over this country is not possible or necessary. The cross-breaking test is decidedly necessary; we cannot do without it, not only to determine the breaking strength, but to inspect the interior of the bricks for voids, fire checks, and laminations. The water-absorption test is of vital importance, as we all know, because water and its freezing are more damaging to pavements than traffic.

REPORT OF COMMITTEE C-4 ON STANDARD SPECIFICATIONS AND TESTS FOR CLAY AND CEMENT SEWER PIPES.

The work of the Committee during the past year has included the increasing and completion of its membership, which is now believed to be representative of all the interests involved and of all sections of the country. Certain schedules of requirements for sewer pipe, as presented in the last annual report, have been submitted to the members of the Committee for discussion. Other schedules are being prepared. Considerable additional data relating to the crushing strength of sewer pipe, including the largest sizes made, have been obtained by tests conducted by members of the Committee, and all recent information available from European sources is being collected by the Chairman, who is now in Europe. The Committee is also considering the extension of its work to include an investigation of tile for agricultural and other drainage purposes, exclusive of sewage, if this shall be found to be properly within its scope.

Material progress has been made during the past year in systematizing the work to be undertaken, and it is believed that the Committee is now, for the first time, in a position to take up in a suitable manner the many complex questions involved in its work, which must be fully considered before an entirely satisfactory report can be submitted. It is the purpose of the Committee to dispose of as many of these questions during the coming year as its facilities and definite knowledge of the subject will permit.

As stated in the last annual report, the work is rendered more difficult by reason of the unsettled state of opinion, with regard to certain phases of the matter, which exists both in this country and abroad among those who have given the most attention to it. The Committee intends to examine as fully as possible all the causes which have contributed toward these differences of opinion in the past, and to consider how they may be best eliminated or minimized in the future.

Respectfully submitted on behalf of the Committee,

A. J. PROVOST, JR.,
Vice-Chairman.

E. J. FORT,
Secretary.

REPORT OF COMMITTEE D-1 ON PRESERVATIVE COATINGS FOR STRUCTURAL MATERIALS.

The investigations on preservative coatings have broadened to such an extent as to require a re-organization of the Committee with a very material enlargement of the membership. It was necessary to define the lines of investigation and state clearly the results which it was hoped to accomplish. To this end the following rules and statement of policy of Committee D-1 were adopted:

RULES OF COMMITTEE D-1.

1. The Officers of Committee D-1 shall be a Chairman, a Vice-Chairman, and a Secretary, to be elected annually.

2. Members may be added to Committee D-1, at any time, by appointment by the Advisory Committee after approval by the Executive Committee of the Society.

3. The following standing sub-committees and their chairmen shall be appointed by the Chairman of Committee D-1, abolishing all old sub-committees:

(*a*) Advisory committee of six to act with the Chairman, Vice-Chairman, and Secretary, for the Committee between meetings.
(*b*) On inspection of the Havre de Grace Bridge.
(*c*) On inspection of the wooden panels at Atlantic City.
(*d*) On the steel fence at Atlantic City, to collaborate with sub-committee of Committee A-5.
(*e*) On linseed oil.
(*f*) On the definition of terms used in paint specifications.
(*g*) On the influence of pigments on corrosion.
(*h*) On accelerated tests.
(*i*) On varnish.
(*j*) On testing white paints.

The chairman of each sub-committee shall be designated by the Chairman of Committee D-1.

The Chairman of Committee D-1 shall appoint such other committees as may be necesssary.

4. All actions taken by Committee D-1 shall be subject to review and approval by the Executive Committee of the Society.

5. Three regular meetings of Committee D-1 shall be held: one at the annual meeting of the Society, one in November, and one in May of each year.

6. Absence from two consecutive regular meetings without notice to the Chairman or Secretary shall be considered as a resignation.

7. The policy of the Committee is that no reports of committee work be made public except over the Chairman's signature.

STATEMENT OF PLAN AND POLICY OF COMMITTEE D-1.

Committee D-1, on Preservative Coatings for Iron and Steel, was organized in 1902 to investigate the problem indicated by the title. The work of the Committee has broadened however during the past few years so as to cover the preservation of materials of construction in general by paint and similar coatings. To meet these conditions the Executive Committee of the Society at its last meeting extended the scope to be covered by the work of the Committee, so that it is now a "Committee on Preservative Coatings for Structural Materials." The growth and importance of the Committee's work, furthermore, have been such that the Committee has been re-organized with an Advisory Committee having executive powers, and a number of sub-committees with powers to investigate, etc., along specific lines.

It has become evident to the members of the Committee that its membership should be enlarged by adding thereto technical men of ability and experience who are interested in preservative coatings, so that the Committee would become an organization of paint chemists and experts within the American Society for Testing Materials. It is thought such a plan of organization will enable its members to confer with reasonable frequency on technical questions. These conferences, say three times a year, will be of inestimable value in aiding the work of the Committee.

In order that the work of the Committee shall develop on broad lines, and be of the greatest practical value in its field of investigation, it is most desirable that the experimenters be trained

observers who appreciate the need of accurate observations and accurate methods of testing before expressing positive conclusions or recommending definite specifications. In this way the integrity and impartial position of the Committee will be maintained and all interested will be assured of just consideration. This plan does not involve any suppression of facts, but rather a clear distinction between facts and conclusions. There should be no hesitation in reporting facts and recommending definite specifications when the established facts warrant positive conclusions.

It is to be hoped that manufacturing and consuming interests will recognize the importance of the work which we are doing, and that they will see the advisability of helping in this work by having technical representation on the Committee.

It was also decided that the reports of the standing committees are hereafter to be presented by their respective chairmen, in their natural sequence.

The reports of various sub-committees are given in the appendix to this report.

Respectfully submitted on behalf of the Committee,

S. S. VOORHEES,
Chairman.

G. W. THOMPSON,
Secretary.

APPENDIX.

REPORT OF SUB-COMMITTEE B ON INSPECTION OF THE HAVRE DE GRACE BRIDGE.

PHILADELPHIA, PA., June 8, 1910.

MR. S. S. VOORHEES,
Chairman, Committee D-1, American Society for Testing Materials,
Washington, D. C.

Dear Sir:

The recent inspection of the Havre de Grace Bridge was held on May 5, under the following program.

The examination of the panels was divided generally into three heads, viz:

A—Chalking,
B—Checking, Cracking, Alligatoring, etc.,
C—General Surface condition,

with a marking for each, as follows:

Excellent	10 to 8
Good	8 to 6
Fair	6 to 4
Poor	4 to 2
Failure	2 to 0

As far as possible, members of the Sub-Committee were requested to pair off with such other members of Committee D-1 who were present, though not of the Sub-Committee on Inspection. Those of the Sub-Committee present were: *W. A. Aiken, Chairman, *G. W. Thompson, *M. MacNaughton, *A. P. Hume, Anderson Polk, A. H. Sabin, *Wirt Tassin. Those marked with an asterisk (*) sent in individual reports. Mr. A. H. Sabin was the only one who collaborated with any other member of the Sub-Committee; he was with the Chairman, who also was accompanied by Mr. Gibboney, of Committee D-1. Mr. Anderson Polk has failed to hand in any report, stating that he had mislaid his notebook.

The results of the inspection are given in the Table of Ratings. The individual marks were averaged from all nine panels, covering three rates of spreading.

REVIEW.

Under A (chalking) the average rating of 18 paints was 8.8, fairly excellent; of one paint 3.6, poor.

Under B (checking, etc.), the average rating of 18 paints was 9.6, nearly excellent; of one paint 3.5, poor.

Under C (general condition), the average rating of 14 paints was 9.1, fairly excellent; of two paints 7.7, quite good; of one paint 6.6, good; of one paint 5.3, very fair; of one paint 3.6, poor.

TABLE OF RATINGS.

*Paint.	Examined for	Aiken.	MacNaughton.	Tassin.	Thompson.	Hume.	Average.	Remarks.
1	A	8	8	10	6	10	8.4	Fairly excellent.
	B	10	10	10	10	10	10.0	Excellent.
	C	7.55	7	6	6	6.66	6.6	Fairly good.
2	A	8	9	1†	8	9	8.5	Fairly excellent.
	B	10	6	1†	8	9	8.2	Fairly excellent.
	C	6.44	6	1†	4.33	4.66	5.3	Fair.
3	A	8	10	8.33	6	7	7.9	Very good.
	B	10	10	10	10	10	10.0	Excellent.
	C	8.33	8	7.67	6	8	7.6	Quite good.
4	A	10	6	10	6	7	7.8	Very good.
	B	10	9	10	10	10	9.8	Nearly excellent.
	C	8.13	9	10	8	9	8.8	Fairly excellent.
5	A	10	10	10	8	10	9.6	Nearly excellent.
	B	10	10	10	10	10	10.0	Excellent.
	C	8.66	8	10	8	9	8.7	Fairly excellent.
6	A	10	10	10	6	9	9.0	Fairly excellent.
	B	10	10	10	10	10	10.0	Excellent.
	C	9	9	10	8	9	9.0	Fairly excellent.
7	A	9	8	10	8	9	8.8	Fairly excellent.
	B	10	10	10	10	10	10.0	Excellent.
	C	8.78	8	10	8	9	8.7	Fairly excellent.
8	A	10	9	10	8	9.66	9.2	Nearly excellent.
	B	10	10	10	10	10	10.0	Excellent.
	C	9.55	9	10	7.33	9	9.0	Fairly excellent.
9	A	10	9	10	8	9	9.2	Fairly excellent.
	B	10	10	10	10	10	10.0	Excellent.
	C	9.22	9	10	6	9	8.6	Fairly excellent.
10	A	8	9	10	6	9	8.4	Very good.
	B	9	6	10	6	9	8.0	Very good.
	C	10	9	10	8	9	9.2	Fairly excellent.
11	A	9	9	10	6	7	8.2	Very good.
	B	9	6	10	7.14	9.66	8.4	Very good.
	C	10	8	10	7.14	9	8.8	Fairly excellent.
12	A	9	10	10	8	9	9.2	Fairly excellent.
	B	10	10	10	10	10	10.0	Excellent.
	C	9	10	10	8	10	9.4	Nearly excellent.
13	A	8	10	10	8	9	9.0	Fairly excellent.
	B	10	10	10	10	10	10.0	Excellent.
	C	8.55	7	10	6	9	8.1	Very good.
14	A	9	9	10	8	8	8.8	Fairly excellent.
	B	10	9	10	10	10	9.8	Nearly excellent.
	C	10	8	10	6	9	8.6	Fairly excellent.
15	A	3	5	4	4	2	3.6	Poor.
	B	2.66	5	4	4	2	3.5	Poor.
	C	2.66	5	3	2.66	4.66	3.6	Poor.
16	A	9	10	10	8	8.33	9.0	Fairly excellent.
	B	10	10	10	10	10	10.0	Excellent.
	C	10	9	10	8	9	9.2	Fairly excellent.
17	A	9	10	10	8	9	9.2	Fairly excellent.
	B	10	6	9	10	9	8.8	Fairly excellent.
	C	8.11	6	8.66	8	8.66	7.9	Very good.
18	A	9	10	10	8	10	9.4	Nearly excellent.
	B	10	10	9.33	10	10	9.9	Excellent.
	C	10	8	10	8	10	9.2	Nearly excellent.
19	A	9	10	10	8	9	9.2	Fairly excellent.
	B	10	8	9.66	10	9	9.3	Fairly excellent.
	C	10	8	10	8	8	8.8	Fairly excellent.

* The compositions of these paints are given in the *Proceedings*, 1908, Vol. VIII, pp. 173 ff.

† These values were not considered in computing the average for Paint No. 2.

The general condition of the bridge proper was, by the majority of the individual reports, considered better than similar panels, even slightly so in the case of the paint marked "poor" throughout. One fact is emphasized—that the importance of proper preparation of the receiving surface and the application of the paint cannot be too thoroughly insisted on, as demonstrating in this test that these two features are essential to provide protection, and possibly are of more importance than the quality of the preservative coating. While this expression might appear inconsistent with the fact that the plate surfaces were very specially prepared before the application of paint, it must also be realized that the preparation of the bridge structure proper was also special in a measure, as compared with ordinary conditions of practice; first, in that these surfaces had an additional preliminary shop priming coat of oil, and were much better cleaned at the time of field painting than such structures generally are; second, in that there was no absolute concordance of the spreading rate on the bridge proper with any of the rates used on the plates, the paint coat of the bridge being probably much heavier than even that obtained through the lowest square-foot rate on the panels; and third, in that the conditions of exposure during application were not identical, the plates being painted indoors and held there until dry, while the bridge proper was of course exposed to the weather at all times. There are numerous and more or less pronounced indications which impressed the Sub-Committee, both individually and generally, that important changes are on the eve of development in many of the panels; but the consensus of opinion is now that it would be unsafe to predict anything positively at this time, as the paints generally are today affording excellent protection.

It had been expected to have photographs made of the plates, or certain of them, at this time, both before and after the removal of the films, but it was concluded as the result of our inspection that the time has not yet arrived for such examination.

Respectfully submitted,

W. A. AIKEN,

Chairman, Inspection Committee, Havre de Grace Bridge.

REPORT OF SUB-COMMITTEE C ON INSPECTION OF THE WOODEN PANELS AT ATLANTIC CITY.

PHILADELPHIA, PA., May 23, 1910.

MR. S. S. VOORHEES,

Chairman, Committee D-1, American Society for Testing Materials,
Washington, D. C.

Dear Sir:

In accordance with your instructions a final inspection of the wooden-panel test fence at Atlantic City was made on April 15 and 16 by the Sub-Committee, with the following in attendance: Messrs. Aiken, Heckel,

Job, Sabin, Voorhees, and P. H. Walker. It was decided by the Sub-Committee to base the inspection upon the condition of each panel as regards (1) Chalking, (2) Cracking or checking, and (3) General surface conditions, indicating the condition in each instance numerically from ten to zero by the following scale:

Excellent	10 to 8
Good	8 to 6
Fair	6 to 4
Poor	4 to 2
Failure	2 to 0

Relative chalking was estimated by rubbing each panel with a piece of black velvet, and observing the whitening of the latter. It is realized that this test gives only general indications, especially when applied to surfaces exposed to the direct action of rain, since at the time of an inspection some of the chalking which had resulted might have been washed away. The indications, however, upon panels similarly exposed should be fairly comparable. The extent of checking or cracking was determined by careful examination of each panel with a magnifying glass, and the general surface condition was judged by viewing each panel carefully from a distance of about six feet.

WEST EXPOSURE.

	Chalking.	Cracking or Checking.	Surface.
W 1	8	8	8
W 145	7	7	8
W 3	9	7	6
W 147	6	7	7
W 5	6	7	7
W 149	7	6	7
W 7	6	8	7
W 176	8	7	7
W 9	9	8	7
W 175	8	7	7
W 11	9	9	7
W 180	8	8	7
W 13	8	9	7
W 181	5	9	8
W 15	8	8	8
W 182	5	9	8
W 17	9	2	2
W 177	6	7	8
W 19	6	6	6
W 178	6	8	7
W 21	7	6	6

	Chalking.	Cracking or Checking.	Surface.
W 168	3	9	8
W 23	7	7	6
W 170	10	8	8
W 25	4	8	7
W 169	10	8	7
W 27	6	7	7
W 172	10	3	5
W 29	6	4	2
W 31	7	4	6
W 33	4	6	6
EAST EXPOSURE.			
W 2	8	8	8
W 146	8	8	8
W 4	6	8	8
W 148	6	6	6
W 6	8	8	7
W 150	8	8	8
W 8	5	9	8
W 10	9	8	8
W 12	10	9	8
W 14	8	9	9
W 16	8	8	8
W 18	10	5	5
W 20	8	8	8
W 22	6	7	8
W 24	8	6	7
W 26	7	8	8
W 28	9	7	8
W 30	8	7	8
W 32	8	7	7
W 34	6	8	8

In the foregoing Report of Inspection, the numbers correspond to the following formulas:

Number.	Ingredients.	Per cent.
W 1	Basic carbonate, white lead	34.0
	Zinc oxide	66.0
W 145	Basic carbonate, white lead in oil	75.0
	Zinc oxide	25.0
W 3	Basic carbonate, white lead	50.0
	Zinc oxide	50.0

Number.	Ingredients.	Per cent.
W 147	Basic sulphate, white lead in oil	75.0
	Zinc oxide in oil	25.0
W 5	Basic carbonate, white lead	25.0
	Basic sulphate, white lead	20.0
	Zinc oxide	45.0
	Calcium carbonate	10.0
W 149	Basic carbonate, white lead	67.0
	Zinc oxide	19.05
	Asbestine	3.5
	Calcium carbonate	10.0
W 7	Basic carbonate, white lead	48.5
	Zinc oxide	48.05
	Calcium carbonate	3.0
W 176	Zinc oxide	30.0
	Special silica	30.0
	Basic carbonate, white lead	15.0
	Basic sulphate, white lead	25.0
W 9	Basic carbonate, white lead	22.0
	Zinc oxide	50.0
	Calcium carbonate	2.0
	Aluminum and magnesium silicates	26.0
W 175	Basic carbonate, white lead	38.95
	Lead sulphate	4.81
	Zinc oxide	33.58
	Calcium carbonate	19.48
	Barytes and silica	3.18
W 11	Zinc oxide	64.0
	Barytes	36.0
W 180	White lead	37.5
	Lead sulphate	7.84
	Zinc oxide	25.87
	Calcium carbonate	20.36
	Barytes and silica	8.42
W 13	Basic carbonate, white lead	43.0
	Zinc oxide	57.0
W 181	Basic carbonate, white lead (type B)	100.0

Number.	Ingredients.	Per cent
W 15	Basic carbonate, white lead	38.0
	Zinc oxide	48.0
	Silica	14.0
W 182	Basic carbonate, white lead (type C)	100.0
W 17	Zinc oxide	73.0
	Silica	25.0
	Calcium carbonate	2.0
W 177	Basic carbonate, white lead (type A)	100.0
W 19	Basic carbonate, white lead	44.0
	Zinc oxide	46.0
	Calcium carbonate	5.0
	Magnesium silicate	5.0
W 178	Zinc lead	100.0
W 21	Basic carbonate, white lead	50.0
	Zinc oxide	50.0
W 168	Sublimed white lead	100.0
W 23	Basic carbonate, white lead	60.0
	Zinc oxide	34.0
	Inert pigment	6.0
W 170	Zinc oxide	90.0
	Calcium carbonate	10.0
W 25	Basic sulphate, white lead	60.0
	Zinc oxide	27.0
	Magnesium silicate	10.0
	Calcium carbonate	3.0
W 169	Zinc oxide	61.0
	Barytes	39.0
W 27	Basic carbonate, white lead	25.0
	Basic sulphate, white lead	20.0
	Zinc oxide	25.0
	Calcium sulphate	25.0
	Calcium carbonate	5.0
W 172	Zinc oxide (ground in special oil)	100.0

Number.	Ingredients.	Per cent.
W 29	Zinc-lead white	30.0
	Zinc oxide	40.0
	Basic carbonate, white lead	20.0
	Calcium carbonate	10.0
W 31	Basic carbonate, white lead	33.0
	Zinc oxide	33.0
	Barytes	34.0
W 16	Basic carbonate, white lead	38.0
	Zinc oxide	48.0
	Silica	14.0
W 18	Zinc oxide	73.0
	Silica	25.0
	Calcium carbonate	2.0
W 20	Basic carbonate, white lead	44.0
	Zinc oxide	46.0
	Calcium carbonate	5.0
	Magnesium silicate	5.0
W 22	Basic carbonate, white lead	50.0
	Zinc oxide	50.0
W 24	Basic carbonate, white lead	60.0
	Zinc oxide	34.0
	Inert pigment	6.0
W 26	Basic sulphate, white lead	60.0
	Zinc oxide	27.0
	Magnesium silicate	10.0
	Calcium carbonate	3.0
W 28	Basic carbonate, white lead	25.0
	Basic sulphate, white lead	20.0
	Calcium sulphate	25.0
	Zinc oxide	25.0
	Calcium carbonate	5.0
W 30	Zinc-lead white	30.0
	Zinc oxide	40.0
	Basic carbonate, white lead	20.0
	Calcium carbonate	10.0

Number.	Ingredients.	Per cent.
W 32	Basic carbonate, white lead	33.0
	Zinc oxide	33.0
	Barytes	34.0
W 34	Barytes	13.0
	Blanc fixé	4.0
	Asbestine	3.0
	Zinc oxide	43.0
	Basic carbonate, white lead	37.0

We understand that this is to be the final official inspection of the fence, and recommend that the Sub-Committee be discharged.

Respectfully submitted,

ROBERT JOB,
Chairman, Sub-Committee C.

REPORT OF SUB-COMMITTEE E ON LINSEED OIL.

The Sub-Committee on February 4, 1910, sent the following letter to all the manufacturers of linseed oil in the United States, enclosing with this letter a copy of the report of Committee E* as reported at the last annual meeting:

"On behalf of Committee E of the American Society for Testing Materials, I am sending you a copy of its report as presented at the last meeting of the Society. I would call your special attention to the report of the Sub-Committee on Linseed Oil. This linseed-oil report contains a large amount of information which should be of value to the linseed-oil industry. May I ask you, after reading this report, to write me on the following points:

"First: Would you be willing to accept the specifications suggested by this Committee, on page 164, for American linseed oil? Also, would you accept them for oil made from imported seed?

"Second: How far would you advise on, or be willing to agree to, specifications for quality of linseed oil based on the tests for turbidity and foots, the moisture and volatile matter, and the free acid number? Any suggestions you may offer on this point will be appreciated.

"Third: Many of the tests which are included in the work of this Committee were found to give discordant results. We refer particularly to the acetyl value, hexabromide, and oxygen absorption tests. It is to be hoped that we can get some of our universities and colleges to investigate these tests and develop scientific methods. Any influence you may exert or suggestions you can offer in this direction would be very helpful to the Committee's work.

* This committee is now designated Committee D-1.—ED.

"Fourth: How far would a flash point test be advisable for either purity or quality?

"Fifth: What would you advise as to specifications for boiled linseed oil? Should a boiled oil contain any rosin or rosin derivatives as shown by the Liebermann-Storch test? And what percentage of rosin would you permit? Should the amounts of lead and manganese present be specified? Also, should boiled-oil specifications have a minimum specific gravity? What would you advise that this minimum should be?

"If there are any other matters relative to this subject on which you would care to comment, we wish you would kindly do so."

This letter was followed up with other letters urging a reply, and we also had published in the technical trade papers a statement containing inquiries similar to the above, and giving our provisional recommendations of specifications for the purity of raw linseed oil and the methods to be used for testing.

Some communications have been received in reply to these letters, etc., from which we would draw the following conclusions:

The manufacturers of linseed oil think it better that more work should be done on the examination of linseed oil from different crops of seed before adopting specifications. It has been suggested by some that our specifications are too rigid and that the linseed oil made from the 1909 crop of flaxseed is lower in iodine number than that of the prior year. In accordance with this suggestion we are having samples taken of the linseed oil crushed from the 1909 crop of seed and will have these tested as soon as practicable. We also hope to have current samples taken during the crushing of the 1910 crop of seed to note whether variations in the oil produced occur with the age and maturity of the seed.

There seem to be reasonable grounds for expecting that specifications for the quality of linseed oil based on tests for turbidity, foots, moisture, volatile matter, and acidity, would be acceptable to the manufacturers of linseed oil and would be valuable to the consumer.

The large consumers of linseed oil have not so far communicated with the Sub-Committee expressing their views on the above questions as fully as could be desired. The Sub-Committee will endeavor to secure from consumers during the coming year more cooperation in this work.

There seems to be some difference of opinion as to the desirability of permitting the presence of rosin in boiled linseed oil; but there is reasonable agreement that the amount of rosin permissible should be limited. There is fair agreement that rosin oil and mineral oil should not be permitted at all. The Sub-Committee will give these matters very careful consideration, and it is hoped that in due time the question of specifications for boiled oil will reach a satisfactory conclusion.

Portions of the samples of oil taken in 1909 from the 1908 crop of seed have been furnished various investigators who have agreed to study these samples for the purpose of endeavoring to develop better methods of determining the acetyl value, hexabromide number, drying value, oxygen absorption tests, etc. Other portions of these samples are still available to investigators who desire to give them careful examination.

Respectfully submitted on behalf of the Sub-Committee,

G. W. THOMPSON,
Chairman.

REPORT OF SUB-COMMITTEE G ON THE INFLUENCE OF PIGMENTS ON CORROSION.

June 15, 1910.

MR. S. S. VOORHEES,
Chairman, Committee D-1, American Society for Testing Materials,
Washington, D. C.

Dear Sir:

At a meeting of Sub-Committee G, appointed to consider the influence of pigments on corrosion, the possible factors which enter into the problem were discussed and the methods proposed for measuring the influence of pigments on corrosion were fully considered. It was decided that relatively large quantities of ten representative pigments available for use in paints for the protection of iron and steel be obtained, and that each member of the Sub-Committee be supplied with samples of these pigments both in the dry state and when ground in linseed oil. Each member of the Sub-Committee will then subject these pigments to corrosion tests by the method which he considers most promising. The results of the individual members will remain unbiased by the results of other members, and a year from now the combined results will form the basis of a report.

Yours very truly,
(Signed) W. H. WALKER,
Chairman, Sub-Committee G.

REPORT OF SUB-COMMITTEE I ON VARNISH.

PHILADELPHIA, PA., June 14, 1910.

MR. S. S. VOORHEES,
Chairman, Committee D-1, American Society for Testing Materials,
Washington, D. C.

Dear Sir:

In accordance with your request, I take pleasure in submitting on behalf of Sub-Committee I the following summary of the Sub-Committee's report which was submitted to the full Committee:

Sub-Committee I has addressed a number of varnish manufacturers and technical consumers, setting forth the desire of the Committee to devise a form of specifications for varnish which will, on the one hand, enable the manufacturer to understand the requirements of the consumer, and which, on the other hand, will enable the consumer to ascertain within a reasonable degree of accuracy how closely such specifications have been fulfilled. Much interesting information has been collated from these sources, and there is promise that practical results will be obtained therefrom. During the coming year, the Sub-Committee will endeavor to formulate this information and place it before a select number of experts for practical test.

This report, therefore, is merely a report of progress, but the Sub-Committee hopes by the time of the next meeting to have information of value to lay before the members.

Yours very truly,
G. B. HECKEL,
Secretary, Sub-Committee I.

[For Discussion of this Report, see page 87.]

REPORT OF COMMITTEE D-2 ON STANDARD TESTS FOR LUBRICANTS.

This Committee began work with its present organization in 1906, with the sending out of a circular letter as to what had better be the first object of its investigation. Several members of the Committee have been obliged to resign on account of pressure of other work or withdrawal from the Society; they have, however, signified their willingness to cooperate in an advisory capacity. The chairman regrets that it has happened, for family and business reasons, that he has been unable to meet with the Committee, and, consequently, has had to rely upon correspondence—a most unsatisfactory means of arousing enthusiasm.

It being the unanimous opinion that the determination of viscosity should first receive attention, half-gallon samples of oils of viscosities varying from 50 to 2,500 seconds were sent to each member of the Committee through the good offices of Messrs. Gray, Pew and Taber, to whom the chairman would again express his thanks. The members were asked to determine the viscosity with all the instruments at their command at the standard temperatures for those instruments. This comparison of the results obtained by various viscosimeters afforded an opportunity to observe the advantages and disadvantages of each and thus make a recommendation as to the best one; but it also gave a chance to construct a set of curves whereby the readings of one instrument can be converted into those of another. No doubt similar ones are in the possession of some of the larger oil-producing or oil-consuming companies, but they are not generally accessible. The results are shown in the tables and in Figs. 11 to 15, inclusive, these are given in detail so that the variations obtained with the various viscosimeters can be seen. With the curves, horizontal distances (abscissas) are in the same scale and refer to seconds on the Saybolt "A" or the Saybolt "C" instrument, so that a comparison of the various instruments can be made not only with that instrument, but, what is equally important, with each other. For example: 150 seconds Saybolt "A" at 70° F. equals 440 seconds

Engler; also, it equals 285 seconds Redwood. Therefore, 440 seconds Engler equals 285 seconds Redwood, and so on. But, the Saybolt reading divided by its water value does not equal the Engler reading divided by its water value. By plotting on one figure the results of all tests at one temperature, we can compare not only a given viscosimeter with the Saybolt viscosimeter, but with the other viscosimeters on that curve as well.

The determination of viscosity is truly in a most unsatisfactory condition for several reasons. In this country it is most commonly done by the Saybolt instrument, of which there are no less than four varieties, A, B, C, and Universal, used at four different temperatures—70°, 100°, 130°, 212° F. To still further complicate matters, none of them are obtainable in the open market; or only recently so. Could anything be more unscientific or unreasonable? Nothing is easier than a comparison of these with some other, such as the Engler, and this has been done by many oil dealers.

In England, the Redwood viscosimeter is the standard; in Germany and most continental countries, the Engler is most commonly used; while in France, the Ixometre Barbet is the one most usually employed, and in Italy it is Pagliani's viscosimeter. This has resulted here in the use of many different instruments, of which the more common are the Engler, the Tagliabue, the Scott and the Pennsylvania Railroad Pipette. These will be described later.

As has already been said, the Engler is the standard instrument of Germany and Austria-Hungary, has been recommended by the International Committee for testing lubricants, and is used by many departments of the United States Government. It is the most carefully made and tested instrument; it is also the most easily manipulated and most sensitive, and your Committee suggests for the present that viscosities of oils and similar substances be determined with this instrument, and expressed in terms of the water value for each instrument, making a correction for specific gravity. In case it be desired to express viscosity in terms of absolute measure, it can be done by conversion tables.

In the Tagliabue viscosimeter the change of head is too great,—as is also the case in the Saybolt,—the orifice is outside the heating bath, and last, but not least, there is absolutely no surety

that the viscosities obtained by it will bear any relation to the Saybolt, which is claimed for it, or can be duplicated with another instrument.

With the Scott instrument, there is no capillary jet proper, so that the results perhaps represent more closely times of efflux rather than viscosity.

The Pennsylvania Railroad Pipette, as is well known, suffers from the serious disadvantage that instruments can be made which will give identical results for water and widely varying results for oil.

Besides sending out samples of oil, a sample of glycerin of known strength was sent to each member; from which it was intended that solutions of glycerin of known absolute viscosities should be prepared, and thus the various viscosimeters standardized in terms of absolute measure. This has been done by these observers and their results do not agree particularly well. A means of checking this work is found in the curve given in Holde* for the Engler viscosimeter and also in some work which some of the students of the Massachusetts Institute of Technology have done.

DESCRIPTION OF THE VARIOUS VISCOSIMETERS.

THE SAYBOLT VISCOSIMETERS.†

This is made in four forms, A, B, C, and the Universal. Apparatus "A" is the standard for testing Atlantic red, paraffin, and other distilled oils at 70° F.; "B", for testing black oils of 0°, 15°, 25°, and 30°, cold test, and other reduced oils up to, but not including, summer cold test oil, at 70° F. Apparatus "C" is used for testing reduced, summer, cylinder, filtered cylinder, XXX valve, 26.5° Bé., and other heavy oils at 212° F. The standard Universal Viscosimeter is used for testing cylinder, valve, and similar oils at 210° F., reduced black oils at 130° F., spindle, paraffin, red, and other distilled oils at 100° F.

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*" Untersuchung der Mineralöle und Fette."

† Redwood, *Jour. Soc. Chem. Ind.*, 5, 124 (1886). Devised by George M. Saybolt, Chemist of the Standard Oil Company. Description from Gill, pp. 27–33 incl.

Apparatus "A."

(*a*) *Description.*—The "A" apparatus (Fig. 1) consists of a brass tube, *T*, containing about 66 cc., and about 3 cm. in diameter and 8 cm. long, forming the body of the pipette. It is connected at the bottom with a smaller tube, *t*, having a window, *W*. This pipette is screwed into the piece, *P*, carrying the jet, 1.75 mm. in diameter; the lower part of this piece is expanded at the bottom to admit of the insertion of a cork. The upper part of the pipette is perforated with a number of small holes leading to a gallery, *G*, 5 cm. in diameter and 1.3 cm. deep. This enables

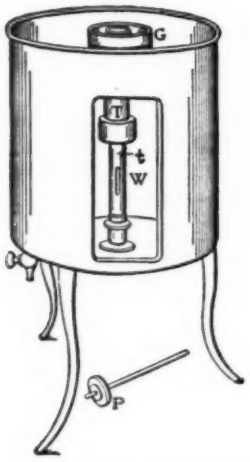

FIG. 1.—Saybolt "A" Viscosimeter.

a workman to fill the apparatus to the same point every time. This pipette is held by *P* in a tank of water 18 cm. high and 20 cm. in diameter, also provided with windows to observe the efflux of the oil. A tin cup with spout, thermometer, pipette with rubber bulb, stop-watch, and beaker for waste oil, complete the outfit.

(*b*) *Manipulation.*—Having the bath of water prepared at 70° F., and the oil in the tin cup about 69.5°, clean the tube out with some of the oil to be tested by using the plunger sent with the instrument. Place the cork air-tight in the lower outlet tube and pour the oil into the tube proper until it flows into the overflow

cup. Bring the oil to exactly 70° by stirring with the thermometer, remove the thermometer, and draw with a pipette the surplus oil in the overflow cup down below the overflow holes. The temperature still remaining constant, with the watch in the left hand, draw the cork with the right and simultaneously start the watch. Towards the end of the run, watch the peep-hole closely through the window in the bath, and stop the watch at the first appearance of space not filled with oil in the glass outlet tube.

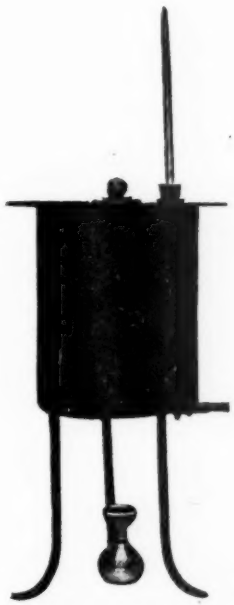

FIG. 2.—Saybolt "C" Viscosimeter.

Apparatus "C". (Standard for testing at 212° F.)

(*a*) *Description.*—This is very similar to the preceding apparatus. The top is closed around the oil gallery, Fig. 2, the windows omitted, and a steam connection provided. The quantity of oil is determined by allowing it to run into a 60-cc. graduated flask. The size of the jet is $\frac{3}{64}$ in.*

* Stillman, *Jour. Anal. and App. Chem.*, 5, 322 (1891).

(*b*) *Manipulation.*—Fill the bath with water and attach the steam inlet to the bottom cock. The upper outlet is for exhaust and overflow. With the water boiling and the bath thermometer registering 212° F., and the oil to be tested having been put through the strainer into one of the tin cups, pour some of the oil into the tube and clean out with the plunger sent with the instrument; never use other than the plunger in cleaning.

Place the cork air-tight in the lower outlet tube, and pour the oil into the tube until it overflows into the overflow cup. Allow the oil to heat until the thermometer reads 210° F., stirring the oil with the thermometer during the heating. Having the bath at 212° and the oil not below 210°, remove the thermometer. Draw the surplus oil from the overflow cup with a pipette down to and below the overflow holes; this insures a positive starting-point.

Place the 60-cc. flask under and directly in a line with the outlet jet, and as close to the jet as it is practicable, to permit of room for drawing the cork. With the watch in the left hand, draw the cork with the right and simultaneously start the watch. The time required for the delivery of 60 cc. is the viscosity. The tube should be cleaned out before each test with some of the oil to be tested.

Notes.—Instead of timing the oil as given in the directions above, the writer has found it better to start the watch, and the instant the second-hand crosses the sixty-second mark, to twist out the cork with the right hand.

The tube should be cleaned out before each test with some of the oil to be tested, using the plunger *P* for this purpose. Black oils or any oil containing sediment should be carefully strained before testing or "running," as it is technically termed. The instruments should be carefully guarded from dust when not in use.

The Universal Viscosimeter (Fig. 3).

(*a*) *Description.*—This is similar to Apparatus "C," just described; in addition to the steam connection it is provided with a ring burner for heating by gas. Sixty cubic centimeters of oil are run through it as with the preceding instrument.

It may be used for testing cylinder, valve, and similar oils with the bath at 212° F. and oil at 210°; for testing reduced, black oils, bath and oil at 130°; for testing spindle, paraffin, red, and

other distilled oils, bath and oil at 100°. When used for testing at 212°, it may be used with either gas or steam alone or both in combination. If with both, the steam may be introduced slowly, more for its condensation to replace evaporation than for real heating purposes, depending upon the gas flame to reach the boiling point, and keeping it there during the operation of test. The bath vessel should always be kept full during a test, whether at 212°, 130°, or 100°. When testing 130° or 100°, gas alone is

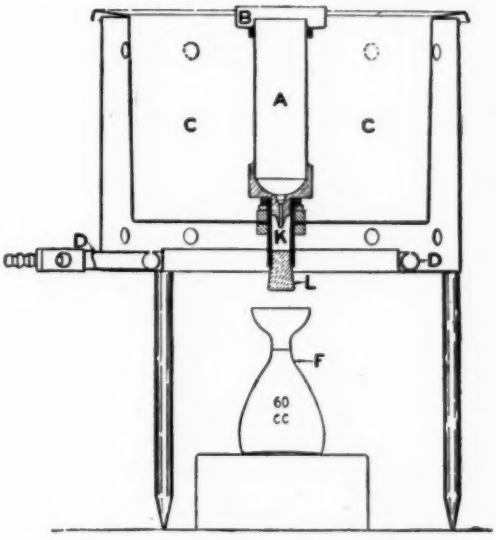

FIG. 3.—Saybolt Universal Viscosimeter.

used to bring the bath to the prescribed temperature, and is turned off during the operation of test, since the large size of the bath usually permits making one test without reheating.

(*b*) *Manipulation.*—1. Have the bath of water prepared at the prescribed temperature.

2. Have the oil strained into one of the tin cups, in which cup it may be heated up to about the standard temperature.

3. Clean out the tube with some of the oil to be tested by using the plunger sent with the instrument.

4. Place the cork (as little distance as possible) into the lower outlet coupling tube, just enough to make air-tight, but not far

enough to nearly touch the small outlet jet of the tube proper ($\frac{1}{8}$ to $\frac{1}{4}$ in. may be enough).

5. Pour the oil from the tin cup (again through the strainer) into the tube proper until it overflows into the overflow cup up to and above the upper edge of the tube proper.

6. Now again see that the bath is at the prescribed temperature.

7. Bring the oil to the standard temperature by stirring with the thermometer sent with the instrument.

8. Remove the thermometer.

9. Draw from the overflow cup, with a pipette, all the surplus oil down to and below the upper edge of the tube proper. This insures a positive starting head.

10. Place the 60-cc. flask under and directly in line with the outlet jet, and as close to the coupling tube as is practical to permit of room for drawing the cork.

11. With the watch in the left hand draw the cork with the right, and simultaneously start the watch.

12. The time required in the delivery of 60 cc. is the viscosity.

13. No drill or other instrument should ever be used in the small outlet jet of the tube proper.

The results obtained with this instrument are not the same in many cases as those obtained with the A, B, and C instruments, nor do they seem to have been adopted by the trade generally.

It is worth noting that three or four per cent. of water does not apparently influence the viscosity.

ENGLER'S STANDARD VISCOSIMETER.*

(*a*) *Construction.*—This instrument is shown in Fig. 4. The inner oil vessel, *A*, is made of brass, gilt inside, and has a lid which carries the thermometer *c*. In the center of the concave bottom is the jet, 20 mm. long, 2.9 mm. in diameter at the upper end, tapering to 2.8 mm. at the lower end; it is made of platinum for standard work, but for ordinary work brass is used. The plug valve *b*, of hard wood, which closes the jet, passes through a tube fixed in the lid, and can be raised without removing the cover.

* Devised by Prof. C. Engler, Carlsruhe. Description from Archbutt and Deeley, "Lubrication and Lubricants," pp. 151 and 152.

Three pointed studs, *C*, fixed at equal distances above the bottom of the vessel, indicate the proper height of the oil, and at the same time serve for leveling the instrument; they mark a volume of 240 cc. The outer bath, *B*, is filled with water when working at temperatures not exceeding 50° C.; above that temperature, a heavy mineral oil is used, which can be heated by means of the ring burner *D*. The oil flowing from the jet is received in the measuring flask, which has a mark at 200 cc. and another at 240 cc.; or it may be divided as shown in Fig. 4 into 100- and 200-cc. flasks, or even into 50- and 100-cc. flasks.

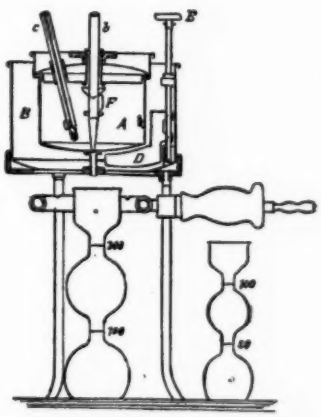

FIG. 4.—Engler Viscosimeter.

(*b*) *Method of Standardizing.*—This is done with water at 20° C. The vessel, *A*, is first thoroughly rinsed out successively with ether, alcohol, and water, the jet being cleaned by means of a feather or a roll of paper. After the water has drained out, the jet is closed by the valve. The measuring flask is filled to the 240-cc. mark with water at 20° C., which is then poured into the oil cup *A*, and should fill it exactly to the level of the studs after the flask has been well drained. The outer bath should be previously filled with water at 20° C. Having adjusted the surface level, if necessary, by taking out or adding a few drops of water, the temperature of the water both inside and outside the cup is brought exactly to 20° C., and then, after allowing time for the water in *A* to become perfectly still, the plug valve is raised and

the water allowed to flow from *A* into the dry measuring flask. The time of efflux will be from 50 to 52 seconds, if the instrument has been made of the standard dimensions given in the figure. The test must be repeated, and the mean of three experiments which do not differ by more than 0.5 second is the efflux time of water at 20° C. The nearest whole number is taken as the unit.

(*c*) *Method of Experiment.*—In testing oils, the vessel, *A*, and the jet are first thoroughly rinsed with alcohol, then with ether, and dried. The oil, previously strained or filtered to remove suspended matter and water, is poured into *A* up to the level of the studs, and is stirred by the thermometer until the desired temperature has been reached. The liquid in *B* is adjusted to the same temperature. After allowing the oil in *A* to become perfectly still, the plug is raised, and the time required for the outflow of 200 cc. of oil is noted. Supposing the efflux time of water at 20° has been found to be 54 seconds, and the sample of oil required 360 seconds at 50° and 90 seconds at 150°; then the

$$\text{Specific viscosity (Engler) at } 50^\circ \text{ C.} = \frac{360}{54} = 6.66,$$

$$\text{" " " " } 150^\circ \text{ C.} = \frac{90}{54} = 1.66.$$

What Engler calls the "specific viscosity" is, of course, a purely arbitrary number, obtainable by this type of instrument alone, and only by such of these as are constructed of the proper dimensions. Instruments recognized by Engler as reliable may be obtained from C. Desaga of Heidelberg, and bear the official mark of the Karlsruhe Chemisch-Technische Versuchsanstalt or the Charlottenberg Technische Anstalt. Engler's viscosimeter has been adopted by the Committee of the German State Railways.

Holde* finds that in testing thick oils time may be saved by collecting 50 or 100 cc. instead of 200 cc., the results when multiplied by 5 or 2.35, respectively, being concordant with those obtained in the ordinary way. He also suggests that the oil bath should be covered, and a reflux condenser attached so as to condense and return the vapor; liquids of fixed boiling-point, such as aniline (184° C.) and naphthalene (217° C.), might then be used for high temperature experiments.

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* *Jour. Soc. Chem. Ind.*, XV (1896), p. 138.

REDWOOD'S STANDARD VISCOSIMETER.*

(*a*) *Construction.*—This instrument (Fig. 5) consists of a silvered copper cylinder *A*, about $1\frac{7}{8}$ ins. in internal diameter and $3\frac{1}{2}$ ins. deep, having a thick metal bottom, slightly concave on the inside, in the center of which the agate jet, *J*, is fixed. In the instrument used by the authors the passage drilled through the jet is 12 mm. in length, and very nearly 1.7 mm. in diameter. Slight unavoidable variations in the jets of different instruments,

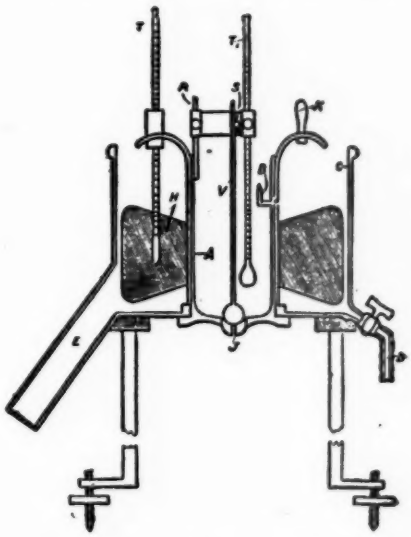

FIG. 5.—Redwood's Viscosimeter.

causing a few seconds' difference in the rate of flow, are corrected by slightly varying the height of the pointed stud *B*, which determines the initial head of the oil. A small brass ball-valve fixed to a wire *V*, when resting in the hemispherical cavity in the agate jet, closes the orifice; when raised so as to allow the oil to flow out, it is suspended, by a small hook, from the stud *S*. The cylinder *A* is fixed, by means of a screw thread and leather washer, in the center of the brazed copper vessel *C*, which is furnished with a tap

* Devised by Boverton Redwood. Description from Archbutt and Deeley, "Lubrication and Lubricants," pp. 144, 145, 146 and 147.

D, and a copper heating tube *E*, projecting at an angle of 45° from the side, close to the bottom. This vessel contains water or oil, by means of which the temperature of the oil in *A* is maintained constant, and is provided with a stirring apparatus consisting of four light metal vanes *H*, fixed to a thin copper tube which revolves smoothly round the cylinder *A*, the tube having a broad curved flange at the top to prevent any of the liquid in *C* from being splashed into the oil in *A*. The stirrer is rotated to and fro by means of the handle *K*, and carries with it the thermometer *T*, which registers the temperature of the fluid bath. Another thermometer, T_1, held by a spring clamp which slides on the rod *R*, is immersed in the oil undergoing test. The instrument is supported on a tripod stand furnished with leveling screws.

(*b*) *Method of Experiment.*—The interior of the cylinder *A* and the orifice are first inspected. They must be perfectly clean, dry, and free from any loose particles which might obstruct the free flow of the oil. In examining the jet, a small mirror held below is useful. After inspection the instrument is leveled. The outer vessel, *C*, is then filled with water or heavy mineral oil, according to the temperature at which the viscosity is to be determined, water being used for all temperatures up to about 200° F. The height of the liquid in *C* should be slightly above that of the oil in *A*. The temperature of the water bath, having been adjusted, is maintained constant during the test by continual stirring, the thermometer being closely watched and any tendency of the mercury to rise or fall corrected by additions of colder or warmer water, the excess of water being drawn off through the tap *D*. Temperatures much above the normal are maintained by heating the tube *E*, by means of a gas or spirit flame. The oil to be tested, if quite clear and bright, is next poured into *A* until the point of the stud *B* is just covered, the jet being first closed by the valve; if the oil is not clear, or if it is a dark-colored oil, it must first of all be strained through fine wire gauze or muslin. Thick oils may be warmed before straining, but they must not be heated more than a few degrees above the temperature at which the test is to be made. The oil should be brought to nearly the required temperature before being poured into the viscosimeter, because the adjustment afterwards takes place slowly. The thermometer T_1 is immersed in the oil to such a depth that the bulb does not

become uncovered during the test, and it is not afterwards moved. A narrow-necked flask, holding 50 cc. to a mark on the neck, is placed below the jet to receive the oil. If the test is to be made at a temperature more than a few degrees above or below that of the air of the room, the flask must be immersed in a bath of liquid heated to the testing temperature, or the body of the flask may be surrounded by a thick layer of cotton-wool contained in a beaker, the neck and graduation-mark being left exposed to view. As there is generally a slight leakage from the valve *V*, the flask should not be placed in position until the last moment.

When both thermometers register the desired temperature, the height of the oil in *A* is finally adjusted so that the point of the stud *B* lies exactly in the surface, and the measuring flask is placed under the jet. The valve *V* is then raised, a stop-watch being started at the same moment, and the number of seconds occupied in filling the flask up to the 50 cc. mark is ascertained. This completes the test. In important cases, and always if the operator be inexperienced, the oil should be poured back into *A*, a little more being added to bring it up to the mark, and the test repeated, the measuring flask being first rinsed out with ether and dried. Duplicate tests ought not to differ more than about one per cent.; greater differences will probably be caused by neglecting to maintain a constant temperature.

(*c*) *Method of Standardizing.*—This instrument is standardized with refined rape oil; but, as different samples of genuine rape oil vary in viscosity, Redwood has proposed the adoption of the arbitrary number 535, which is the average number of seconds required by 50 cc. of rape oil to flow out of his viscosimeter at 60° F. The relative viscosity at *x*° F. of any oil, compared with the viscosity at 60° F. of rape oil of density 0.9142,* which is taken as 100, is then found by the following formula:

$$\text{Relative viscosity (rape oil at } 60^\circ \text{ F.} = 100) = \frac{td\ 100}{535 \times 0.9142},$$

where *t* is the number of seconds required for the outflow of 50 cc. of the oil at *x*° F., and *d* is the density of the oil at the same temperature.

* 0.9142 = Sp. gr. 0.915 at $\frac{60^\circ}{60^\circ}$ F.

It will be observed that Redwood compares oils at all temperatures with rape oil at 60° F.; some prefer to make the comparison with both oils at the same temperature.

TAGLIABUE VISCOSIMETER.*

This instrument (Fig. 6) has been specially devised with a thorough knowledge of lubricating oils, and the requirements of manufacture and trade. It is thus made to meet all demands as a measure of viscosity, without the many objections to all other

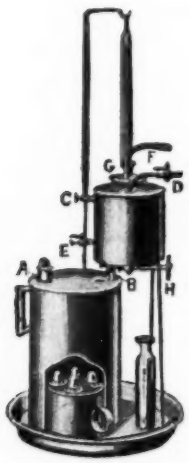

FIG. 6.—Tagliabue Viscosimeter.

devices for this purpose. It is intended to show the viscosity of any oil by noticing the number of seconds required for 50 cc. to run through the open faucet. This corresponds to the most generally approved standard now in use by the largest refiners.

(*a*) *To Test the Viscosity of Oils at 212° F.*—Pour water into the boiler through an opening *A* (Fig. 6), after unscrewing the safety valve until the water gage shows that the boiler is full. See that the stop-cock *B* is open, making direct connection between the boiler and upper vessel which surrounds the receptacle in which the oil to

* Devised by C. J. Tagliabue, instrument maker to the Standard Oil Company. Description from C. J. Tagliabue's catalogue, 1898, p. 117.

be tested is placed. Place a wire holder in the set-nut *C* and suspend the thermometer so that the bulb will be about $\frac{1}{4}$ in. from the bottom of the oil bath. Then after carefully *straining* 70 cc. of the oil to be tested, which of course must be warmed in the case of very heavy oils, pour it into the oil bath. Close the stop-cocks *D* and *E*. Screw the extension *F* with rubber hose attached into the coupling *G* and let the open end of the hose be immersed in a vessel of water, which will prevent too large a loss of steam. Place a lamp or Bunsen burner under the boiler; screw a steel nipple marked 212 on to the stop-cock *H;* the apparatus is now ready to use. After steam is generated, wait until the thermometer in the oil bath shows a temperature of from 209° to 211° F.; then place the 50-cc. test glass under the stop-cock *H* so that the stream of oil strikes the side of the test glass, thereby preventing the formation of air bubbles; and when the thermometer indicates its highest point, open the faucet *H* simultaneously with the starting of the watch which is supplied with each instrument.

When the running oil reaches the 50 cc. mark in the neck of the test glass the watch is instantly stopped, and the number of seconds noted. Then multiply the number of seconds by two, and the result will be the viscosity of the oil. For example: if 50 cc. of oil runs through in 101.5 seconds the viscosity would be 203. It is necessary to keep the oil well stirred before making the test in order to have it at a uniform temperature. It is also best to repeat the test until sufficient skill is attained by practice for uniform results.

(*b*) *To Test the Viscosity of Oils at 70° F.*—Screw the steel nipple marked 70 on to the faucet *H;* close the stop-cock *B*, closing communication between the boiler and upper vessel; also close the stop-cock *E*. Fill the upper vessel through the opening *G* with water at a temperature as near 70° as possible, also having the oil to be tested at the same temperature; hang the thermometer in position, and after stirring the oil thoroughly, blow through the rubber at *D* to thoroughly mix the water. Should the thermometer show higher or lower than 70°, add cold or warm water until the desired temperature is attained. Then proceed as before.

Note.—In making tests at 70° F. it is absolutely necessary that the temperature of the oil should be fully 70° before starting the run.

PENNSYLVANIA RAILROAD OR DUDLEY PIPETTE.*

The Dudley pipette, as shown in Fig. 7, is a 100-cc. pipette with a mark on the stem both above and below the bulb; the viscosimeter is placed in a closed box provided with a glass door, and during the test the temperature in the box is kept at the same temperature as the oil. This is of the greatest importance in taking the viscosity with an instrument of this kind.

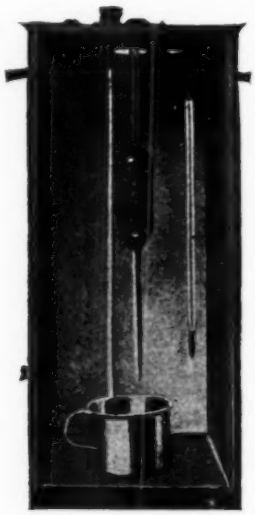

FIG. 7.—Pennsylvania Railroad or Dudley Pipette.

THE "SCOTT" VISCOSIMETER.†

The "Scott" Viscosimeter (Fig. 8) is used for determining the relative thickness or fluidity of liquids. It is simple in construction; will not rust; is easily operated; can be taken apart and thoroughly cleaned; will never get out of repair; and is adapted to practical use. This instrument may be used for thin or thick liquids, thus enabling the operator to determine comparative relations between light and heavy specific gravity solutions, as well as thin and thick liquids. A thick or gummy liquid is said

* Description from *Jour. Ind. and Eng. Ch.*, 2, 178.
† Description from the directions sent with the instrument.

to be viscid; at the same time it may be either high or low in specific gravity; therefore, viscosity is the measurement of the *thickness* of a liquid, while specific gravity is only measurement of the *weight* of the liquid.

Temperature is a very important feature in determining the viscosity of a liquid. Strictly speaking, temperature has a greater influence on viscosity than any other physical constant, even a tenth of a degree variation changing the viscosity to quite an extent, especially in very thick liquids. For very accurate work, the temperature should be regulated to a fifth of a degree; especially is this true where check determinations are required. For commercial purposes, the temperature is generally regulated to one

FIG. 8.—Scott Viscosimeter.

degree, which is considered close enough, but it is, of course, not absolutely accurate.

In determining the viscosity of a liquid in this instrument, the following method of procedure should be strictly observed:

First, measure out in a graduate exactly 200 cc. of the liquid; then empty into the viscosimeter cup, leaving the graduate to drain for ten or fifteen minutes. The brass arm with the instrument is designed to support the graduate while inverted.

When the liquid is in the cup, place the thermometer in position in this cup and after about two minutes note the temperature. If the surrounding temperature is lower than the temperature at which the viscosity is to be taken, it will be necessary to fill the

water bath, or outer vessel, with hot or warm water, in order to bring the temperature of the oil or other liquid in the viscosity cup up to the required figure. A thermometer in the water bath will help to regulate the adjustment and should register within three or four degrees of the desired temperature. When the liquid in the viscosity cup has attained the exact temperature required, keep it at this point for two or three minutes, occasionally stirring the liquid in the viscosity cup to insure a uniform temperature.

Now place a 50-cc. glass cylinder under the oil hole, or tube, in the viscosity cup; hold the stop-watch in one hand and with the other hand press down on the lever which operates the plunger, thus opening the oil hole and allowing the liquid to run into the 50-cc. cylinder. The moment the liquid reaches the 50-cc. mark on the glass cylinder, stop the watch, after which the lever may be released and the flow of liquid stopped. The number of seconds required for a flow of 50 cc. of any liquid at a given temperature is the "time viscosity" of such a liquid.

The time viscosity, or the number of seconds divided by the water figure (i. e., the number of seconds required for a flow of 50 cc. of distilled water at 60° F.), gives the "specific viscosity." Every viscosimeter has the water figure stamped on the handle of the viscosity cup. All viscosity determinations should be reported as specific viscosity, which enables one to compare the thickness of a liquid with water. As an example we may take the following determinations. The viscosimeter in use we will say has a water figure of 10.8 seconds. Having run an oil which took 43.2 seconds, we obtain a time viscosity of 43.2. Dividing 43.2 seconds by the water figure (10.8 seconds), we get a specific viscosity of 4.00; consequently the oil is four times as thick as water.

In scientific research work it is sometimes necessary to take into account the effect of specific gravity on viscosity, in which case we obtain what is called "gravimetric viscosity." To determine the gravimetric viscosity, simply divide the specific viscosity by the specific gravity of the liquid in question. For all practical purposes, specific viscosity is the determination used.

Viscosity may be determined on a liquid at any temperature. Custom, however, has established certain temperatures for different liquids, which are generally fixed at the normal temperature of the

room, of the machine, or that temperature under which the liquid is supposed to be treated practically.

Some liquids require only one temperature for the determination of viscosity; for instance, water, milk, alkalies, acids, spirits, etc.; and this temperature may be either 60° or 70° F. (60° F. is considered as the normal temperature; 70° F. is the usual temperature of a house or work shop and is spoken of as a normal "room" temperature). Oils are usually subjected to two or more temperatures for determination of viscosity; thus an oil at 70° F. may show a given viscosity and each succeeding rise of say ten degrees will give a perfect viscosity curve; but at a definite high temperature, the oil will break and the viscosity drop abruptly, after which the curve of viscosity will remain in nearly a straight line.

The following temperatures for different commercial liquids have been established as a standard for viscosity determinations:

1. Machine, engine and dynamo oils ..... 70° and 120° F.
2. Cylinder, valve and crank case oils ..... 18°, 212° and 300° F.
3. Linseed and other paint oils..... 70° and 120° F.
4. Molasses, glycerin and sugar solutions ..... 70° F.
5. Varnish, japan, etc. ..... 70° F.
6. Waxes and greases ..... 180° and 212° F.
7. Glue and gelatin solutions ..... 90° F.

Glue and gelatin are always made up as a 15-per cent. solution; that is, we soak 50 grams of the glue in about 100 cc. of cold water until softened, then liquefy by means of a water bath and finally make up exactly 200 cc. at 90° with more warm water.

Note.—For a list of viscosities for the various oils, the reader is referred to Mr. W. G. Scott's article on "A Systematic Method of Testing Varnish, Oil, Glue, etc." in *Drugs, Oils and Paints*, Vol. 12, 460 (1897); Vol. 13, 50 and Vol. 14.

*Ostwald's Viscosimeter.**—This is a small glass pipette with a long capillary tube forming one side of a U-tube, the other side of which serves as the collection vessel for the sample after it has run out. Consequently it is easy to repeat the determination.

Reischauer's Viscosimeter is of the glass pipette type; the upper tube projects down into the body of the instrument so that the head is constant.

* Devised by Prof. Ostwald, Professor Emeritus, Leipsic.

Traube's Viscosimeter is also a glass pipette with à very long jet at right angles; the liquid whose viscosity is to be measured is forced out under a constant head of water.

DOOLITTLE'S TORSION VISCOSIMETER.*

(*a*) *Description.*—The apparatus consists of a cylinder (Fig. 9) rotating in the oil, and a graduated disk to measure the amplitude of rotation. These are supported by a fine piano wire from a substantial stand, provided with leveling screws; a

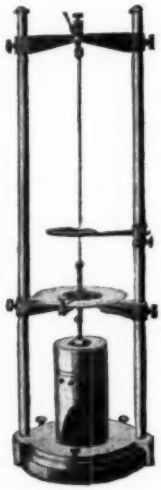

FIG. 9.—Doolittle's Viscosimeter.

lens enables the graduations on the disk to be read more accurately, and a bath filled with water or oil serves to maintain any desired temperature. The instrument should be so adjusted that it will read within 0.5° of the zero point on either side of it when vibrating through an arc of 180°; this can be effected by loosening the set screw at the top and turning the pin which holds the wire.

(*b*) *Manipulation.*—Immerse the friction cylinder in the oil by slipping its stem into the stem of the disk, and adjust the temperature very carefully to the point at which it is desired to

*O. S. Doolittle, *Jour. Am. Chem. Soc.*, 15, 173, 454 (1893), formerly Chemist of Philadelphia and Reading Railroad. Description from Gill, pp. 33, 34 and 35.

determine the viscosity; great care must be taken to keep this temperature constant during the test. Either a water bath or bath of lard oil—according to the temperature desired—may be used. The oil in the cup should cover the cylinder with a layer $\frac{3}{16}$ in. deep when it is swinging freely, and it should be in the center of the cup.

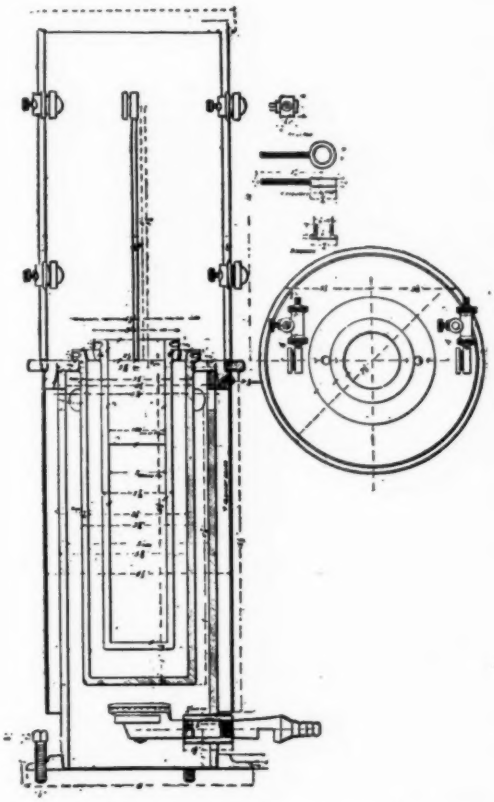

FIG. 10.—Magruder's Plunger Viscosimeter.

By lifting the milled head at the top of the instrument out of the notch, and turning it completely around from right to left until it drops into the notch again, the wire is rotated 360°. By raising the disk by means of the cam the friction cylinder will rotate in the oil by virtue of the torsion of the wire. The disk will rotate 360° and a portion of another arc, which latter is the first

reading. For example, let the reading at the end of the first swing be 355.6° right. The left-hand swing is ignored, and the arc on the next swing to the right is read; let us say, 338.2° right. The retardation produced by the oil is 355.6° − 338.2° = 17.4°. The

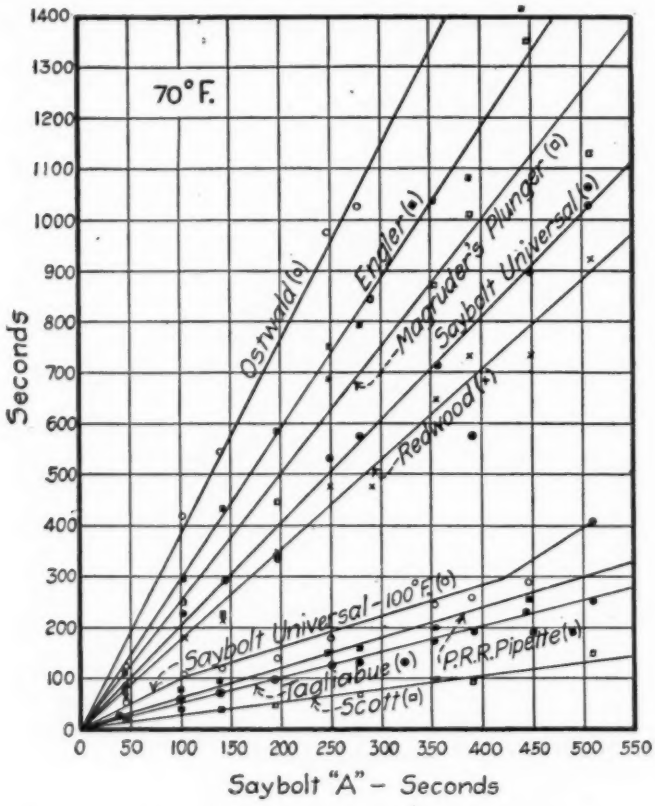

FIG. 11.—Comparison of Various Viscosimeters with the Saybolt "A" Viscosimeter at 70° F.

vibrations should now be stopped, and the head should be turned in the opposite direction and the readings to the left taken, and the average of the two considered as the retardation of the oil.

The results are expressed in the number of grams of sugar contained in 100 cc. of sugar syrup at 60° F., its viscosity being taken at a temperature of 80° F. In the example cited, 17.4° (with the small cylinder) represents a viscosity of 65.6; this means

that if 65.6 grams of granulated sugar were dissolved in water at 60° F., made up to 100 cc., and then heated to 80° F., its viscosity would be the same as that of the oil under examination.

The readings of the first and second swings are to be taken, as later vibrations give different results. The wire and cylinder

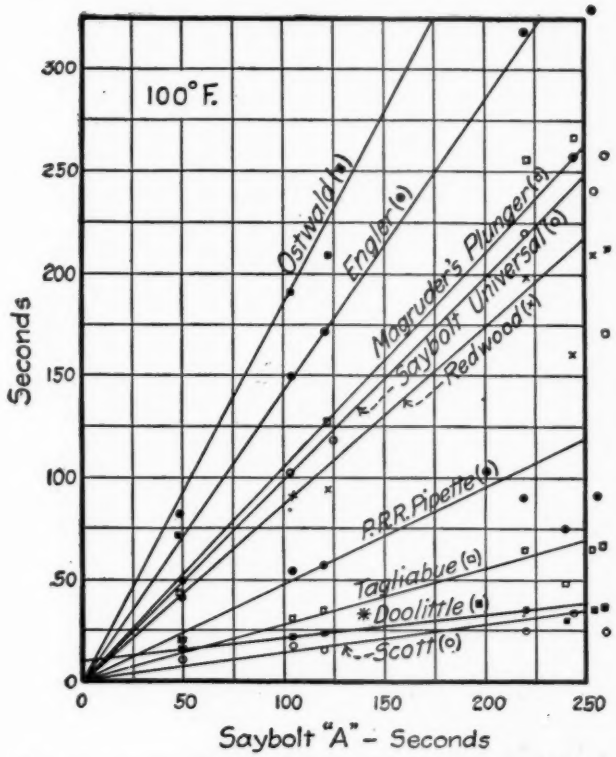

FIG. 12.—Comparison of Various Viscosimeters with the Saybolt "A" Viscosimeter at 100° F.

should be handled with great care, as they are very sensitive to abuse. The wire should be greased with tallow occasionally, and in case of a new instrument, should be re-standardized after six months' use. In case a new wire is inserted the instrument must be re-calibrated. When not in use the zero point should be kept under the index, the disk upon its supports, and the wire without torsion.

* The ordinates to the Doolittle curve are grams of granulated sugar, instead of seconds as with all the others.

MAGRUDER'S PLUNGER VISCOSIMETER (Fig. 10).

It consists, as its name denotes, of a piston or plunger 0.01 in. smaller than the cylinder into which it fits. This is kept at a constant temperature and the time required for the plunger to sink

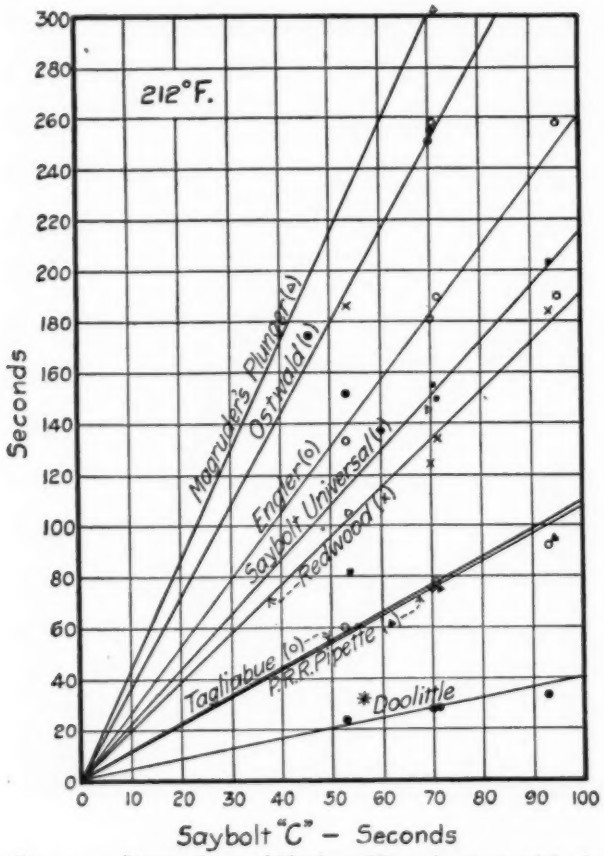

FIG. 13.—Comparison of Various Viscosimeters with the Saybolt "C" Viscosimeter at 212° F.

a certain distance in the oil-filled cylinder is the viscosity of the oil.

For a comparison with the Saybolt viscosimeter, see Fig. 11.

The instrument is an improvement by Professor Magruder of the Ohio State University upon one devised by Mr. C. M. Perkins.†

* The ordinates to the Doolittle curve are grams of granulated sugar, instead of seconds as with all the others.

† *Trans. Am. Soc. Mech. Eng.*, 9, 374.

Stormer's Viscosimeter consists of a paddle rotated by a definite force (a weight falling through a definite distance); the number of rotations of the paddle measures the viscosity of the

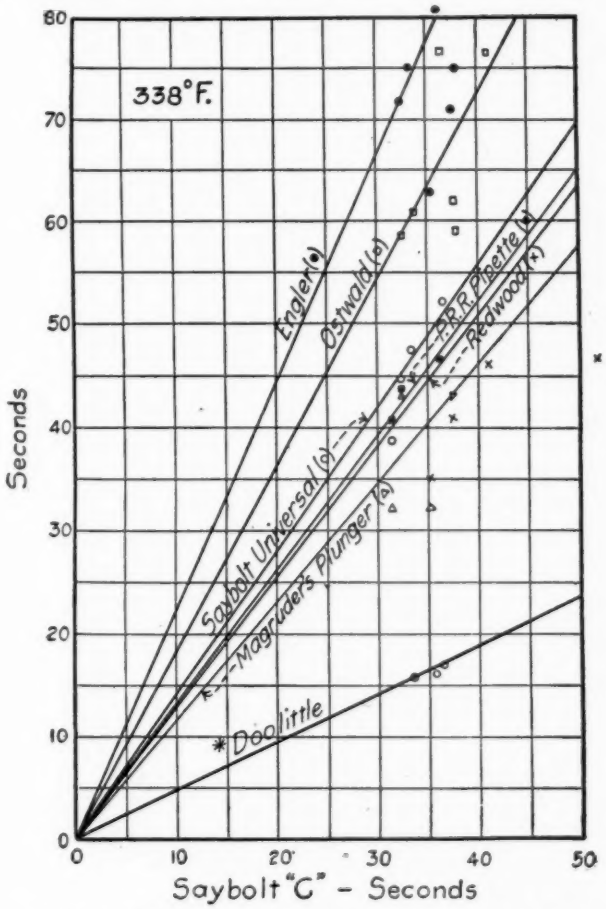

FIG. 14.—Comparison of Various Viscosimeters with the Saybolt "C" Viscosimeter at 338° F.

fluid tested. Being devised for varnishes it is more suitable for thick liquids and is not sufficiently sensitive for oils. It is very similar to that devised some fifteen years ago by Weiss, which Mr. Stormer had not happened to see.

* The ordinates to the Doolittle curve are grams of granulated sugar, instead of seconds as with all the others.

RESULTS AND PLOTS.

These plots are given out tentatively at the present time, as obviously, from so few observations—in some cases only one series—nothing conclusive can be learned. Other series are invited, both from members of the Society as well as from any one into whose hand this report may come. They may be sent to the Chairman, who will from time to time make the necessary corrections

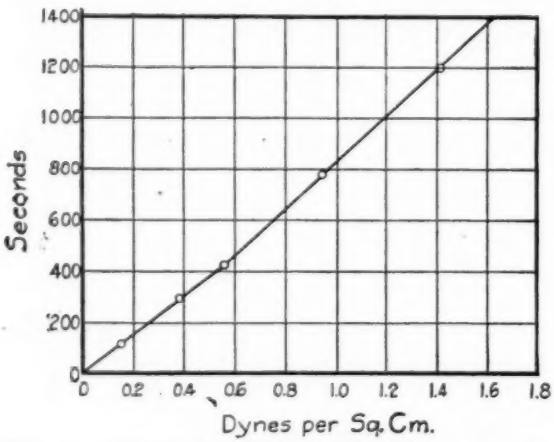

FIG. 15.—Absolute Viscosity. Engler Viscosimeter.

The following tables show the comparison of the various viscosimeters with the same oils.

The characteristics of the oils used are given in Table I.

TABLE I.

Oil.	Specific Gravity at					Flash, ° F.	Fire, ° F.
	60° F.	70° F.	100° F.	212° F.	338° F.		
S 50....	0.869	0.871	0.860	.....	.....	270	278
T B	0.876	0.885	0.874	.....	.....	366	398
S 150...	0.921	0.925	0.913	.....	.....	310	320
G 200...	0.918	0.918	0.906	.....	.....	320	334
S 250...	0.934	0.936	0.918	.....	.....	330	343
T F.....	0.892	0.904	0.894	.....	.....	410	450
S 350...	0.930	0.934	0.921	.....	.....	342	364
G 400...	0.916	0.924	0.914	.....	.....	338	360
S 450...	0.928	0.935	0.923	0.889	.....	342	374
T J.....	0.897	0.907	0.896	0.861	.....	432	486
S 2,500..	0.950	0.950	0.940	0.902	.....	380	435
G 100...	0.901	0.841	0.790	.....	.....	.....	.....
G 150...	0.889	0.835	0.791	.....	.....	.....	.....
T X....	0.892	0.840	0.797	.....	.....	.....	.....
T Y....	0.903	0.842	0.792	.....	.....	.....	.....

TABLE II.—SAYBOLT "A." SECONDS AT 70° F.

Oil.	Observers.			Average.
	Taber.	Gill.	Gillett.	
S 50	48.1	42.0	41.0	44.0
T B	108.0	.....	95.0	101.0
S 150	154.6	136.0	134.0	141.5
G 200	210.4	182.0	.....	196.2
S 250	270.0	242.0	233.0	248.0
T F	287.5	.....	272.0	279.8
S 350	390.0	335.0	337.0	354.0
G 400	403.0	375.0	386.0	388.0
S 450	478.0	431.0	433.0	447.0
T J	530.0	.....	484.0	507.0
S 2,500	3,265.0	2,639.0	.....	2,952.0
Water	.....	25.0	.....	.....

TABLE III.—SAYBOLT UNIVERSAL. SECONDS AT 70° F.

Oil.	Observers.		Average.
	Penniman and Browne.	Davis.	
S 50	75.8	92.0	84.9
T B	232.3	213.0	223.6
S 150	302.9	276.0	289.0
G 200	.....	332.0	332.0
S 250	541.9	521.0	531.0
T F	551.5	592.0	572.0
S 350	744.7	675.0	709.0
G 400	.....	572.0	572.0
S 450	951.9	843.0	897.0
T J	1,049.0	988.0	1,023.0
S 2,500	.....	3,071.0	3,071.0

TABLE IV.—REDWOOD. SECONDS AT 100° F.

Oil.	Observers.		Average.
	Taber.	Gillett.	
S 50	42.0	45.0	43.5
T B	88.1	94.0	91.1
S 150	101.0	105.0	103.0
G 200	132.0	.....	132.0
S 250	156.0	158.0	157.0
T F	198.6	198.0	198.3
S 350	209.8	204.0	206.9
G 400	220.0	228.0	224.0
S 450	252.0	.....	252.0
T J	338.6	.....	338.6
S 2,500	1,231.6	.....	1,231.6

TABLE V.—COMPARISON OF SAYBOLT "A" AT 70° F. WITH SAYBOLT UNIVERSAL AT 100° F.

Oil.	Observers.			
	Penniman and Browne.		Different Observers on Different Sets.	
	70°.	100°.	70°.	100°.
S 50	44.0	50.0	.....	.....
T B	101.0	105.0	100.0	100.0
S 150	142.0	118.0	130.0	125.0
G 200	196.0	140.0	165.0	150.0
S 250	248.0	179.0	195.0	175.0
T F	280.0	223.0	240.0	200.0
S 350	354.0	246.0	280.0	225.0
G 400	388.0	259.0	325.0	250.0
S 450	447.0	290.0	360.0	275.0
T J	507.0	409.0	395.0	300.0
S 2,500	2,952.0	1,197.0	.....	.....

TABLE VI.—SAYBOLT UNIVERSAL. SECONDS AT 100° F.

Oil.	Observers.		Average.
	Penniman and Browne.	Davis.	
S 50	51.8	48.0	50.0
T B	105.6	104.0	105.0
S 150	115.4	121.0	118.2
G 200	.....	140.0	140.0
S 250	178.7	244.0	211.0
T F	225.6	220.0	223.0
S 350	239.3	253.0	246.0
G 400	.....	259.0	259.0
S 450	291.0	289.0	290.0
T J	436.7	381.0	409.0
S 2,500	.....	1,197.0	1,197.0

TABLE VII.—SAYBOLT "C." SECONDS AT 212° F.

Oil.	Observer. Taber.
T I	.....
T Y	93.5
G Y	70.1
T X	71.0
G W	53.2

TABLE VIII.—SAYBOLT UNIVERSAL. SECONDS AT 212° F.

Oil.	Observers.			Average.
	Penniman and Browne.	Gillett.	Davis.	
T J	.....	.....	.....	.....
T X	208.0	201.0	201.0	203.0
T Y	150.0	149.0	149.0	149.0
G W	98.4	73.0	73.0	81.4
G Y	143.6	162.0	162.0	155.9

TABLE IX.—ENGLER. SECONDS AT 212° F.

Oil.	Observers.				Average.
	Penniman and Browne.	Nelson.	Taber.	Gillett.	
T J	.....	89.0	.....	86.0	87.0
T X	226.4	268.0	247.5	290.0	258.0
T Y	174.0	193.0	194.2	200.0	190.3
G W	131.8	137.0	126.0	136.0	132.7
G Y	180.3	186.0	173.2	186.0	181.4
S 450	.....	.....	.....	70.0	70.0
S 2,500	.....	.....	.....	106.0	106.0

TABLE X.—REDWOOD. SECONDS AT 212° F.

Oil.	Observers.		Average.
	Taber.	Gillett.	
T J	.....	52.0	52.0
T X	187.0	182.0	184.0
T Y	136.0	132.0	134.0
G W	83.0	90.0	86.0
G Y	121.5	123.0	122.3
S 450	.....	42.0	42.0
S 2,500	.....	66.0	66.0

TABLE XI.—SAYBOLT UNIVERSAL. SECONDS AT 338° F.

Oil.	Observers.		Average.
	Penniman and Browne.	Davis.	
G W	40.0	37.0	38.5
G V	45.2	44.0	44.6
T X	47.0	.....	47.0
T X Y	51.6	.....	51.6

TABLE XII.—SAYBOLT "C." SECONDS AT 338° F.

Oil.	Observers.		Average.
	Taber.	Jeffers.	
G W	31.5	39.0	35.2
G V	32.5	42.0	37.5
T X	33.7	42.0	37.7
T X Y	36.5	45.0	41.0

TABLE XIII.—ENGLER. SECONDS AT 338° F.

Oil.	Observers.			Average.
	Penniman and Browne.	Nelson.	Taber.	
G W	61.1	.....	66.4	63.7
G V	70.5	.....	71.5	71.0
T X	71.7	78.0	74.9	74.9
T X Y	79.5	87.0	83.2	83.2

TABLE XIV.—REDWOOD. SECONDS AT 338° F.

Oil.	Observers.		Average.
	Taber.	Jeffers.	
G W	36.0	34.0	35.0
G V	40.1	42.0	41.0
T X	42.9	44.0	43.5
T X Y	49.4	43.0	46.2

Respectfully submitted on behalf of the Committee,

AUGUSTUS H. GILL,
Chairman.

C O P

American Society for Te

TO THE MEMBERS OF C

ON STANDARD TESTS FO

Dear Sirs:

At the request of Prof. A

D-2, I am sending you enclosed herew

of the committee to be presented at

of the Society, which includes propo

Lubricants. Prof. Gill instructs

"The report, which embodi
the members, is suggested as
case there be anything wrong,
approve, please return one co
of with an explanatory letter
two weeks of its receipt.
please so state. If no repl
understood that you do not wi

Yo

(Signed)

C O

P Y

or Testing Materials.

Philadelphia, Pa., April 24, 1913.

OF COMMITTEE D-2

TS FOR LUBRICANTS.

rof. A. H. Gill, Chairman, Committee

herewith galley proof of the report

ed at the approaching annual meeting

proposed Provisional Tests for

ructs me to state:

embodies the ideas of many of
d as our annual report. In
rong, or of which you do not
ne copy of the proof corrected
etter to the chairman within
. If it meets your approval
o reply be received it will be
ot wish to serve on the committee."

Yours very truly,

d) Edgar Marburg,

Secretary-Treasurer.

O P Y

Test Mat Proc 1 25372 11 on 12 No 31

REPORT OF COMMITTEE D-2
ON
STANDARD TESTS FOR LUBRICANTS

The committee recommends that the tests for lubricants, appended to this report, be adopted by the Society as provisional. In making these recommendations, the committee feels that it is unwise to be too radical. It has therefore kept the Saybolt universal viscosimeter, the Baumé hydrometer, and the Fahrenheit thermometer, giving their comparison with other instruments where these are not readily obtainable.

Respectfully submitted on behalf of the committee,

AUGUSTUS H. GILL,
Chairman.

J. M. JEFFERS,
Secretary.

AMERICAN SOCIETY FOR TESTING MATERIALS

PHILADELPHIA, PA., U. S. A.

AFFILIATED WITH THE

INTERNATIONAL ASSOCIATION FOR TESTING MATERIALS.

PROPOSED PROVISIONAL TESTS
FOR
LUBRICANTS.

VISCOSITY.

Determined with the Engler Viscosimeter.[1]—In case it is desired to correct for the specific gravity of the oil, the following formula which gives results in specific viscosity can be used:

$$\text{Sp. viscosity} = \text{sp. gr.} \times \frac{\text{time of efflux of oil}}{\text{time of efflux of water}} \times 7.32$$

If it is necessary to use a quantity of oil less than 240 cc., the following quantities can be employed and multiplied by the corresponding factor[2]:

Amount of oil put in, cc.	45	50	60	120
" " " run out, cc.	25	40	50	100
Factor to change to 200 cc. run out and 240 cc. put in	5.55	3.62	2.79	1.65

Standard instruments are carried in stock by Bausch & Lomb, Rochester, N. Y.

Determined by the Saybolt Universal Viscosimeter.—As an alternative instrument the Saybolt universal viscosimeter[3] is recommended: it is preferred by some from experience in its use, and also from the fact that it is so extensively employed in this country. It can be obtained from George M. Saybolt, 26 Broadway, New York City, who vouches for its accuracy. Its dimensions are as follows:

Diameter of overflow filling gage cup	31.0 mm.
Depth of " " " "	13.0 "
Diameter of main cylindrical tube	30.0 "
Depth from starting head to outlet jet	113.0 "
Length of outlet jet	13.0 "
Diameter of outlet jet	1.8 "
Charging quantity	70.0 cc.

The specific viscosity obtained with this instrument is not the same as with the Engler: tables for the conversion of the readings of one instrument into those of the other are in preparation by the United States Bureau of Standards. Meanwhile the comparison by Saybolt can be used, and is given in Table I.

[1] See *Proceedings*, Am. Soc. Test. Mats., Vol. x, p. 124 (1910).

[2] Gans, *Chemische Revue der Fette und Harz-Industrie*, Vol. 6, p. 221 (1899).

[3] See *Proceedings*, Am. Soc. Test. Mats., Vol. x, p. 122 (1910).

TABLE I.—COMPARISON OF VISCOSITY AS DETERMINED BY THE ENGLER AND SAYBOLT VISCOSIMETERS.

Sample No.	Engler. 200 cc. of Oil at 68° F.		Engler. 200 cc. of Oil at 100° F.		Saybolt Universal. 60 cc. of Oil at 100° F.		Greater Viscosity by Saybolt, per cent.
	Time of Efflux, seconds.	Viscosity.[1]	Time of Efflux, seconds.	Viscosity.[1]	Time of Efflux, seconds.	Viscosity.[2]	
312	106	2.00	79	1.49	49	1.66	11
304	304	5.73	146	2.75	101	3.36	29
302	666	12.56	260	4.90	182	6.06	23
317	852	16.06	319	6.02	223	7.43	23
318	1230	23.20	437	8.24	305	10.16	23
306	1300	24.53	451	8.51	313	10.43	22
309	1765	33.30	574	10.83	399	13.30	22
310	2120	40.00	688	12.98	481	16.03	23
Average	.....	.....	.....	11.49	.....	14.37	.....

[1] Compared with 200 cc. of water at 20° C., 53 seconds.
[2] Compared with 60 cc. of water at —° C., 30 seconds.

The points in favor of the Saybolt instrument are:

1. The large ratio of the volume of the bath of water to the volume of oil tested. This is important in keeping the test sample at the desired temperature during the test.

2. The ready means of adjusting the quantity of oil with which the instrument is filled.

3. The simple device for stopping the jet, permitting of no injury to it.

4. The heating device which excludes the danger of superheating the outlet jet.

5. The fact that it uses a smaller quantity of oil, and requires less time than any other viscosimeter.

SPECIFIC GRAVITY.

For all practical purposes there is little to choose between the hydrometer, Westphal balance or Goeckel piknometer, provided these instruments are verified. The observations should be taken with the oil at 15°.5 C. (60° F.) and compared with water at the same temperature. In case this is not feasible, a correction of 0.00063 can be made for each degree Centrigrade, positive, when above and when below 15.5° C.

For conversion into the Commercial Baumé degrees, the formula $\frac{140}{130+Be^{\circ}}$ may be used, subtracting 1° Baumé for every increase of 5°.5 C. above 15°.5 C.

Evaporation Test.

Light Oils (Spindle and Loom Oils).—The object of this test is to determine what percentage of an oil is volatile when exposed to nearly the same conditions as it is on a bearing. The oil is exposed upon annular disks of filter paper $1\frac{5}{8}$ in. in outside diameter, with holes $\frac{5}{8}$ in. in diameter, which have been standing in a sulphuric acid desiccator for several days, contained in a flat watch-glass.

The watch-glass and paper are weighed to tenths of a milligram and about 0.2 g. of oil brought upon it by dropping from a rod, and accurately weighed. The watch-glass is then placed in an air-bath, the temperature of which remains nearly constant at 60° to 65° C. (140° to 150° F.), and heated for 8 hours. It is then cooled and reweighed, the loss in oil being figured in per cent. No oil should be passed which gives an evaporation of more than 4 per cent.

Heavy Oils.—Use Conradson's method in saturated and superheated steam.[1] Or Holde's method[2] may be followed.

[1] *Journal* Industrial and Engineering Chemistry, Vol. 4, p. 744 (1912).
[2] "Untersuchung der Mineralöle und Fette," 2d Ed., p. 137.

This consists in heating a known weight of oil contained in the cup of a Pensky-Marten's flash-point tester in a bath at the boiling point of nitrobenzol, 193° to 195° C., or of anthracene, 305° to 310° C., for 5 hours: the oil is cooled in a desiccator and weighed.

Cold Test.

This has been the subject of careful investigation by a committee of the American Chemical Society. It is recommended that no action be taken until this report is made, and that for the present the following method be used:

Put 1 oz. of the oil to be examined in a 4-oz. vial, insert a short, rather heavy thermometer in it, and place the whole in a freezing mixture. When the oil has become solid throughout, let it stand one hour; remove the vial, allow the oil to soften, and stir thoroughly until it will run from one end of the bottle to the other. The reading of the thermometer is then taken by withdrawing it and wiping off the oil with waste to render the mercury visible.[1]

[1] Dudley and Pease, *The American Engineer and Railroad Journal*, Vol. 69, p. 332 (1895).

Flash and Fire Test.

With the Cleveland Open Cup.—The oil is heated at the rate of 10° F. per minute, and the flash point tested with a small bead flame for every rise of 5° F. The fire test is, as a rule, 50° to 80° F. higher than the flash point. As the open-cup tests are easily affected by drafts, they are subject to errors of 5° F. The thermometers used should be compared with a standard and corrected for stem exposure. When this is done it is suggested that "corr." be added to the reading: thus, "flash 379° F. corr."

Pensky-Martens Test.—Where great accuracy is required the Pensky-Martens tester should be employed. The method of operating is as follows:[1]

[1] Lewkowitsch. "Analysis Fats, Oils and Waxes," 4th Ed., Vol. 3, p. 58.

Referring to Fig. 1, *E* is the oil container, which is placed in a metal heating vessel *H*, provided with a mantle *L* in order to protect the heating vessel from loss of heat by radiation. The oil-cup *E* is closed by a tightly-fitting lid (shown in plan). Through the center of the lid passes a shaft carrying the stirring arrangement, which is worked by means of the handle *J*. In another opening of the cover is fixed a thermometer. The lid is perforated with several orifices, which are left open or covered, as the case may be, by a sliding cover. This can be rotated by turning the vertical spindle by means of the milled head *G*. By turning *G*, an opening of the slide can be made to coincide with an orifice in the cover, and simultaneously a very small flame, burning at the movable jet *E*, is tilted on to the surface of the oil.

The test is performed by filling the oil into the oil-cup up to a certain mark, fixing the cover, and heating the oil somewhat rapidly at first, until its temperature is about 30° C. below the expected flash point. The temperature is then allowed to rise very slowly only, by making suitable use of the wire gauze shown in the figures, so that the rise of temperature within half a minute does not exceed about 2° C. From time to time the milled head *G* is turned and the flame tilted into the oil-cup. The temperature at which a slight explosion is produced is noted as the flash point of the oil.

Soap Test.

The test depends upon the fact that the metaphosphates of the earthy and alkali metals and aluminum are insoluble in absolute alcohol. Five to ten cubic centimeters of the oil are dissolved in 5 cc. of 86° gasolene or ether, and fifteen drops of a saturated solution of "stick phosphoric acid" in absolute alcohol are added, shaken and allowed to stand: the formation of a flocculent precipitate indicates the presence of soap. For the accurate determination of these soaps a known quantity of the oil must be ignited and the residue quantitatively examined.

Saponification Value.

This is expressed by the number of milligrams of potassium hydrate necessary to saponify one gram of the oil. From 2.5 to 10 g. of the oil, according as 65 to 20 per cent of saponifiable matter are supposed to be present, are boiled with 25 cc. N/2 alcoholic potash in a 200-cc. Jena Erlenmeyer flask. A reflux condenser is used and the boiling may require from 5 to 8 hours. The excess of alkali is titrated with N/2 HCl, using phenolphthalein. The strength of the N/2 KOH is determined by boiling 25 cc. in similar flasks alongside of those in which the oil is treated and for the same length of time.

Alcohol purified with silver oxide according to the method of Dunlap[1] should be used, as well as potassium hydrate "purified by alcohol."

[1] *Journal* Am. Chem. Soc., Vol. 28, p. 397 (1900).

Free Acid.

About ten grams of oil are weighed into a 200-cc. Jena Erlenmeyer flask, 60 cc. of neutral alcohol added, the mixture warmed to about 60° C. and titrated with N/6 KOH, using phenolphthalein, the flask being frequently and thoroughly shaken.

The result in case of a mineral oil is usually reported in percentage of sulphuric anhydride, SO_3; with an organic oil, in percentage of oleic acid. It is suggested that it be reported, as with the saponification value, as the number of milligrams of KOH necessary to neutralize the acidity in one gram of oil.

Gumming Test.

This gives an indication of the amount of change that may be expected in a mineral oil when in use. These resinified products increase the friction of the revolving or rubbing surfaces. It is also a measure of the amount that an oil will carbonize in a gas or gasolene-engine cylinder. It is applied after the manner of the elaidin test, by thoroughly mixing together in a cordial glass 5 g. of the oil with 11 g. of nitrosulphuric acid and keeping the mixture cooled in a pan of water at 10° to 15° C. Brownish spots or, in case of a bad oil, masses, form around the edges and become red in the course of two hours.

As has been shown by long practical experience the oil showing the least tar or gum is the best oil; it also absorbs the least oxygen.

The nitrosulphuric acid is made by saturating sulphuric acid of 1.47 sp. gr. cooled to 0° C. with nitric oxide.

Emulsifying Test.

Conradson[1] states that this is a very important test for oils to be used in turbine engines. Some oils emulsify so badly as to clog up the pipe connections, thus preventing a uniform flow of the lubricant.

[1] *Journal Industrial and Engineering Chemistry*. Vol. 2, p. 171 (1910).

Sulphur Test.[1]

Proceed as follows: A portion of a sample, 0.7 to 1.0 g., is burned in a calorimetric bomb containing 10 cc. of water and oxygen under a pressure of 30 atmospheres. A lower pressure sometimes gives inaccurate results. If the sample contains more than 3 per cent of sulphur the bomb is allowed to stand in its water bath for 15 minutes after ignition of the charge. In case the sulphur content is as high as 5 per cent, oxygen under pressure of 40 atmospheres is used. With these high pressures in a Berthelot bomb of 500 to 600-cc. capacity, repeated trials have failed to show even traces of carbon monoxide or sulphur dioxide. If a smaller bomb of about 175-cc. capacity, such as the Peters or Kröker, is used, incomplete combustion from a lack of oxygen may result if too large a sample is taken.

After cooling,—15 minutes is usually enough,—the bomb is opened and its contents are washed into a beaker. If the bomb has a lead washer, 5 cc. of a saturated solution of sodium carbonate is added, the contents are heated to the boiling point, boiled for 10 minutes, and are then filtered. This operation is necessary to decompose any lead sulphate from the washer. The united washings are then filtered, acidified with hydrochloric acid, boiled to expel all carbonic acid, and the sulphuric-acid content is determined in the usual way with barium chloride.

Gravimetric determination is preferred to volumetric, because the nitrogen contained in the air originally in the bomb is oxidized in part to nitroacids, which cause a small error if the volumetric determination alone is used. The sulphur content of any combustible material, from light gasolenes weighed in a tared gelatin capsule to solid bitumens and cokes, can be readily determined by this method.

This method of burning in a bomb is accurate, practicable, and rapid, and is recommended in preference to all of the other methods described. The calorimetric determination, if desired, can be made at the same time.

[1] Allen and Robertson. Technical Paper No. 36, Bureau of Mines, p. 10.

Test for Water.[1]

Dilute the oil with an equal volume of benzene and whirl it vigorously until the separated layer of water does not appear to increase in volume. However, as water is somewhat soluble in any diluent used and also in oils, a portion of the water content will fail to appear; consequently the method in which a diluent is used can not be considered accurate. It is advisable first to agitate the diluent vigorously with water and then to separate with the centrifuge in order to saturate it with water before using.

Groschuff[2] states that 100 gs. of benzene will dissolve 0.03 g. of water at 3° C. and 0.337 g. of water at 77° C., whereas petroleum products (density 0.792) will dissolve from 0.0012 g. at 2° C. to 0.097 g. at 94° C.

[1] Allen and Jacobs. Technical Paper No. 25, Bureau of Mines, p. 5.

[2] E. Groschuff. "The Solubility of Water in Benzene, Petroleum, and Paraffin Oil." Chem. Abs., Vol. 5, p. 2550 (Aug. 10, 1911).

Alternate Method.[1]—The water content may be accurately and conveniently determined during the course of an ordinary distillation in the following manner:

Two hundred grams of the sample are weighed into a one-fourth-liter distilling flask and the distillation carried out in the ordinary manner at the rate of one drop of distillate per second. The distillation can be performed most accurately in an electric still. At temperatures between 90° and 150° C. the water distills over and can be removed from the receivers by means of a micropipette and weighed. Usually a few drops of water adhere to the condenser and fail to run into the receivers; in this event a small pellet of absorbent cotton, moistened with water, squeezed as dry as possible, and weighed, is fastened to a wire and run up into the condenser to remove these last traces of water. The increase in weight of the cotton pellet, figured as water, is added to the weight of the water in the receivers.

With an oil containing considerable water, it is advisable to cause a slow current of dry, inert gas, such as carbonic acid, to bubble through the oil in the distilling flask to carry off the vapors of oil and water as soon as formed. The gas current will reduce bumping and the overheating of the oil to a minimum. The condenser must also be kept well cooled throughout the distillation. This method, with the quantity of sample and the apparatus above mentioned, is accurate to less than 0.03 of one per cent.

Gasolene Test.

Conradson's Method.—Dissolve 10 cc. of the oil in 90 cc. of 86°–88° gasolene (from Pennsylvania crude) in the graduated tube[1] shown in Fig. 2. Allow to stand one hour at 70° F.; not more than 5 per cent. of flocculent or tarry matter should have settled out. If the test is first applied to the oil before making the flash test and again after this test, it shows the extent to which the oil is changed upon heating. Other things being equal, the oil which is changed the least is the best oil.

[1] The flat tube originally proposed by Conradson cannot be obtained in the market.

Microscopical Examination.

Put a few drops of the well-mixed oil on a slide and note the nature of the suspended matter—whether carbonaceous specks, flakes of paraffin, which disappear on warming, or foreign matter. Polarized light is a great aid in detecting paraffin crystals, showing them white on a black background. The polariscope is excellent for this same purpose, showing them when it is impossible to see them with direct light.

Carbon Residue Test.

Gray's Method.—To a tared 1-oz. flask of the dimensions shown in Fig. 3, add 25 cc. of the oil to be tested and weigh. Wrap the neck of flask with asbestos paper as far down as the side arm. Stopper tightly with a good cork. Connect to a small aerial condenser by plugging the space with asbestos or glass wool. Provide a shield which will protect the flame and the flask up to the side tube. Using the flame of a good Bunsen burner, heat the flask so that the first drop of distillate will come over in approximately five minutes. Continue the distillation at such a rate, that one drop will fall from the end of the condenser for every single beat of a metronome set at 60. As the end of the distillation approaches, increase the heat just enough so that no heavy vapors are allowed to condense and drop back into the flask, continue increasing the heat until the flask is enveloped in the flame, and hold the temperature five minutes. Allow the flask to cool, remove the asbestos covering and cork, and burn out completely the carbon and oil in the neck as far down as side tube, and in the side tube. Heat the bottom of the flask until no more vapors are given off. Cool and weigh.

REPORT OF COMMITTEE D-3 ON STANDARD METHODS OF ANALYSIS OF FATS AND OILS.

Since its appointment in May, 1909, the Committee has held two meetings in conjunction with similar committees of the Association of Official Agricultural Chemists and of the American Chemical Society. These committees constitute a Joint Committee on the Unification of the Methods of Analysis of Fats and Oils, which has for its object the representation of this country in the formation, if possible, of an international commission upon this subject, as well as the unification of the methods employed here.

The personnel of the Joint Committee is as follows:

From the Association of Official Agricultural Chemists:

L. M. Tolman (*Chairman*), P. H. Walker, A. Lowenstein.

From the American Chemical Society:

A. H. Gill, David Wesson, C. E. Waters.

From the American Society for Testing Materials:

C. N. Forrest (*Secretary*), G. W. Thompson, J. K. Frank.

The formation of the Joint Committee has been announced in the scientific press of this country and also to the International Commission. Data are now being compiled which cover the work that has already been done by the various committees in our different scientific associations along the line of unification of analyses of fats and oils.

The International Commission now consists of representatives from Germany, Holland, France, Russia, Italy, Sweden and Switzerland, and it proposes to enlist the interest of as many other nations as possible through their scientific societies and perhaps through the national government. Inasmuch as the value of exports and imports of fats and oils is frequently based upon analytical data, it is quite important that there should be an international agreement in the methods employed, and also that

this country should be adequately represented in the event of any steps being taken towards such an agreement. Whether the plans of the International Commission will afford adequate representation is now being considered by the Joint Committee before any definite action towards cooperation therewith is taken.

The work of the Joint Committee is chiefly concerned with glycerides, although the use of glycerides in the arts in conjunction with mineral oils, largely as lubricants, suggests the advisability of an attempt to harmonize those methods of analysis employed in the petroleum industry which are also applicable to the valuation of glycerides. The preliminary investigation has embraced an inquiry by sub-committees into the present methods employed in this country for specific gravity determinations and cold tests, and this work is now being continued. The cooperation of the Bureau of Standards has been secured in connection with the standardization of apparatus and the distribution of samples for cooperative work in the development of methods.

The Committee therefore has the honor of reporting considerable progress in spite of its limited period of existence, and invites correspondence from all members of the Society who are interested in this particular subject.

Respectfully submitted on behalf of the Committee,

C. N. FORREST,
Chairman.

REPORT OF COMMITTEE D-4 ON STANDARD TESTS FOR ROAD MATERIALS.

The Committee on Standard Tests for Road Materials has made considerable progress during the past year. After careful consideration, the method for the determination of bitumen in asphalt paving mixtures, refined asphalts and asphalt cements, which was tentatively presented to the Society in 1906, and tentatively revised in 1909* so as to include all bituminous paving and road materials, is presented to the Society for adoption by letter ballot.†

The Committee, in presenting this method of analysis, wish it understood that they do not recommend it as the best for general use, as it is longer and in several cases gives no better results than other more expeditious methods, but only as a method to be resorted to in case of dispute, as it seems to have the widest range of applicability.

The Committee further recommends that the method for sizing and separating the aggregate in asphalt paving mixtures, as reported to the Society in 1906 and published in the Proceedings for 1906 and 1909,* be put to vote by letter ballot for adoption as standard.

The determination of residual coke in bitumens, as submitted to the Society in 1909,* is also presented for adoption as standard.

Methods for the determination of the loss on heating of oil and asphaltic compounds, and for the determination of the penetration of bitumens, have been revised and are now presented for adoption as standard. These methods in their revised form are appended to this report.

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* See Report of Committee H, Appendix, *Proceedings*, 1909, Vol. IX, pp. 220–224.

† Inasmuch as the recommendations applying to proposed Standard Tests for Road Materials contained in this report of Committee D-4 had not previously been submitted to letter ballot of the Committee, as required by the Regulations Governing Technical Committees, the Secretary was instructed by two-thirds vote at the session at which this report was presented, to refer this and the other recommendations to letter ballot of the Society, provided the previous vote of the Committee by letter ballot should be unanimous. Since that did not prove to be the case, no formal action could be taken toward the adoption of the proposed standard tests by the Society.—Ed.

During the past year the Sub-Committee on Bituminous Paving Materials was sub-divided into special committees to consider individual problems for the purpose of facilitating the investigation of various tests. These special committees were appointed to investigate the following subjects:

1. The nomenclature of bitumens.
2. The determination of ductility, melting or flow point, and apparatus for the determination of the consistency of bituminous materials, both liquid and solid.
3. Method for determining paraffin scale.
4. The investigation of the action and use of different solvents on bitumens.
5. Methods for determining the cementing value of bitumens.
6. Publications.
7. Method of distillation.

The interest manifested in these investigations indicates that during the coming year a number of new tests will be agreed upon and recommended to the Society at the next annual meeting.

The Committee suggests that the following method of distillation, as presented by the special committee on distillation, be put before the Society as a tentative method to be tried out:

PROPOSED TENTATIVE METHOD OF DISTILLATION.

This method is proposed for use in distilling oils, tars, asphalts, and other bituminous materials for use in road construction.

Apparatus.—The apparatus shall consist of the following standard parts:

1. *Flask.*—The distillation flask shall be a standard 150-c.c. Engler distilling flask, having the following dimensions as adopted by the International Petroleum Congress:

Diameter of bulb	6.5	cm.
Length of neck	11.75	"
Diameter of neck	1.6	"
Surface of material to tubulature	9.0	"
Length of tubulature	10.0	"
Angle of tubulature	75°	

A variation of 3 per cent. from the above measurements will be allowed.

2. *Thermometer.*—The thermometer shall be of hardened glass filled with nitrogen under pressure; it shall read to 450° C., and shall have the following dimensions:

Diameter of stem	6.75	to	7.25	mm.
Length of thermometer	335	"	350	"
Length from 0° to 450° marks	285	"	300	"
Length of bulb	20	"	22	"
Diameter of bulb	5.25	"	6 50	"

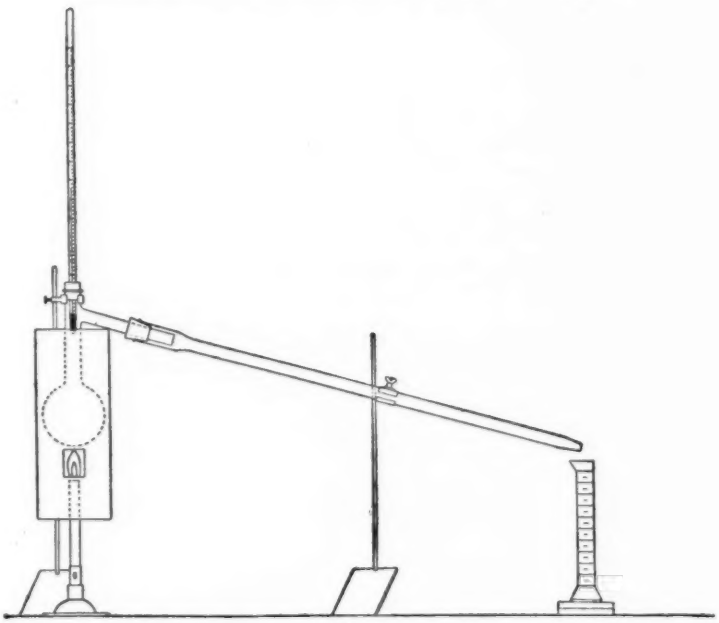

FIG. 1.

It shall rise from 15° to 95° in not less than 3 seconds nor more than 5 seconds when plunged into boiling water.

3. *Condenser.*—The condenser tube shall have the following dimensions:

Length of tube			500	mm.
Width of tube	12	to	15	"
Width of adaptor end of tube	20	"	25	"

4. *Stands.*—Two iron stands provided respectively with one universal clamp for holding the condenser, and one light grip arm with cork-lined clamp for holding the flask.

5. *Burner and Shield.*—Bunsen burner with tin shield 20 cm. long by 7.5 cm. diameter. The shield has a sight hole for observing the flame.

6. *Cylinders.*—The cylinders used in collecting the distillate shall have a capacity of 25 cc., and shall be graduated to tenths of a cubic centimeter.

Setting up the Apparatus.—The apparatus is set up as shown in Fig. 1, the thermometer being placed so that the top of the bulb is opposite the middle of the tubulature. All connections should be tight.

Method.—One hundred cubic centimeters of the dehydrated material to be tested is placed in a tared flask and weighed. After adjusting the thermometer, shield, condenser, etc., the distillation is commenced, the rate being so regulated that 1 cc. passes over every minute. The receiver is changed as the mercury column just passes the fractionating point.

To determine the amount of residue, the flask is weighed again when distillation is complete. During the distillation the condenser tube shall be warmed when necessary to prevent the deposition of any sublimate. The percentages of fractions should be reported both by weight and by volume.

Respectfully submitted on behalf of the Committee,

L. W. PAGE,
Chairman.

PRÉVOST HUBBARD,
Secretary.

APPENDIX.

Proposed Standard Method for the Determination of the Penetration of Bitumen.

The penetration of bitumen shall be the distance expressed in hundredths of a centimeter that a No. 2 needle will penetrate into it direct without friction at 25° C. under a stated weight applied for a stated length of time, the factors of weight and time being determined as follows:

The material shall first be tested for five seconds under a weight of 100 grams. If this result is less than 10 the penetration shall be determined under a weight of 200 grams applied for one minute; if between 10 and 300, the penetration shall be determined under a weight of 100 grams applied for five seconds; if greater than 300, the penetration shall be determined under a weight of 50 grams applied for five seconds. In every case the factor of weight and time shall be stated when reporting the penetration.

It is recommended that the penetration may be determined at 0° and 46° C. in addition to the 25° C. test.

Proposed Standard Method for the Determination of the Loss on Heating of Oil and Asphaltic Compounds.

The loss on heating of oil and asphaltic compounds shall be determined in the following manner: Forty grams of the water-free material shall be placed in a circular tin box with vertical sides, measuring about 1 in. in depth by $2\frac{3}{8}$ ins. in diameter, internal measurement. The penetration of the material to be examined shall, if possible, be determined at 25° C., in the manner heretofore described, and the exact weight of the sample ascertained. The sample in the tin box shall then be placed in a hot-air oven, heated to 170° C., and kept at this temperature for five hours. At no time shall the temperature of this oven vary more than 2° C. from 170° C. When the sample is cooled to normal temperature, it shall be weighed and the percentage of loss by volatilization reported. The penetration of the residue shall then, if possible, be determined at 25° C., as upon the original material, and the loss in penetration found by subtracting this penetration from the penetration before heating.

DISCUSSION.

Mr. Howard. MR. J. W. HOWARD.—There seems to be a tendency in this Society to postpone the making of definite specifications for asphalt, and the determination of the many real tests largely in use. We should establish, among other tests, a test of cementitious or adhesive values of asphalt and bituminous cements for pavements and of bituminous compounds for roads. The penetration test is a measure of consistency or degree of hardness, but the degree of hardness is not really what we wish to know. It is the cementitious or binding strength that is of real value to chemists, cities, and others.

Next year, I should like to see the Committee propose tests for adhesion or cementitious values. The day has come when every one must test asphalt cements and road binders or cements on their merits, without respect to brand. There are many good American asphalts and blends of these and foreign ones. One person may desire cementitious values and results and oppose ductility, because his firm is producing a substance which does not draw out in long strings. Another prides himself on great ductility, but less adhesion. I think it wise if we could determine or define a minimum ductility, which all asphalt cements must meet in order to be acceptable so far as this test is concerned.

REPORT OF COMMITTEE D-7 ON STANDARD SPECIFICATIONS FOR THE GRADING OF STRUCTURAL TIMBER.

The work of the Committee during the past year has been devoted largely to getting the various railways and lumber associations to adopt a standard specification for yellow-pine bridge and trestle timbers as submitted last year. The Committee wishes to report gratifying results along this line. The specification was adopted by both the Southern Yellow Pine Manufacturers' Association and the American Railway Engineering and Maintenance of Way Association, substantially as submitted by your Committee last year. It now remains for the Society to approve these specifications formally, and for this purpose the Committee recommends that a formal vote be taken on the proposed Standard Specifications for Yellow-Pine Bridge and Trestle Timbers for their final adoption as presented in the last annual report. These specifications are appended to this report.

Similar work has been done on standard specifications for Douglas fir and Western hemlock bridge and trestle timbers. In cooperation with the American Railway Engineering and Maintenance of Way Association, a series of specifications have been formulated, which follow herewith. As these specifications have not yet been formally adopted by the manufacturers, your Committee simply presents them as a report of progress, believing that by next year certain small changes will have been made and that the Committee will then be ready to recommend their formal adoption.

Proposed Standard Specifications for Douglas Fir and Western Hemlock Bridge and Trestle Timbers.

(To be applied to single sticks and not to composite members.)

Standard Heart Grade.

1. *Standard Heart Grade.*—Shall include yellow and red Douglas fir and Western hemlock. White Douglas fir will not be accepted.

2. *General Requirements.*—All timbers shall be live, sound, straight and close-grained, cut square-cornered, full length, not more than ¼-in. scant in any dimension for rough timber or ½-in. for dressed timber. Shall be free from large, loose or unsound knots, knots in groups, or other defects that will materially impair its strength for the purpose for which it is intended. All timbers shall be subject to inspection before loading.

3. *Stringers.*—Shall show not less than 90 per cent. heart on each side and edge, measured across the surface anywhere in the length of the piece. Shall be out of wind and free from shakes, splits, or pitch pockets over ⅜ in. wide or 5 ins. long. Knots greater than 2 ins. in diameter will not be permitted within one-fourth the depth of the stringer from any corner, nor upon the edge of any piece; knots shall in no case exceed 3 ins. in diameter.

4. *Caps, Sills and Posts.*—Shall show not less than 85 per cent. heart on each of the four sides, measured across the surface anywhere in the length of the piece. Shall be out of wind and free from shakes, splits, or pitch pockets over ½ in. wide or 5 ins. long. Knots shall not exceed one-fourth the width of the surface of the piece in which they occur, and shall in no case exceed 3 ins. in diameter.

5. *Longitudinal Struts and Girts, X-Braces, Sash Braces and Sway Braces.*—Shall show one side all heart; the other side and two edges shall show not less than 85 per cent. heart, measured across the surface anywhere in the length of the piece.

6. *Ties and Guard Rails.*—Shall show one side and one edge all heart; the other side and edge shall show not less than 85 per cent. heart, measured across the surface anywhere in the length of the piece.

7. *Timbers for Howe Truss Chords.*—Shall show not less than 90 per cent. heart on each side and edge, measured anywhere in the length of the piece. Shall be out of wind and free from shakes, splits, or pitch pockets over ⅛ in. wide or 3 ins. long. Knots shall not be over 1½ ins. in diameter, nor be closer together on each surface than one in any four linear feet; but if knots are 1 in. or less in diameter, one in any three linear feet will be allowed.

STANDARD GRADE.

8. *Standard Grade.*—Shall include yellow, red and white Douglas fir and Western hemlock.

9. *General Requirements.*—All timbers shall be sound and cut square-cornered, except that timbers 10 by 10 ins. in size may have a 2-in. wane on one corner or its equivalent on two or more corners. Other sizes may have proportionate defects. Must be free from defects which will impair its utility for temporary work. Knots shall not exceed one-fourth the width of the surface of the piece in which they occur. All timbers shall be subject to inspection before loading.

10. *Stringers, Caps, Sills and Posts.*—Shall be out of wind, and free from shakes or splits extending over more than one-eighth of the length of the piece. Shall be free from knots more than 4 ins. in diameter; knots greater than 3 ins. in diameter will not be permitted on the edge of any stringer.

Continued interest is being shown by the manufacturers as well as the consumers of Douglas fir and yellow pine in the recommendations made by the Committee, that the quality of timbers be determined in some way by ascertaining the number of growth rings per inch. This has been manifested in the incorporation in many specifications of the recommendation made by the Committee that the density of timber be determined by counting the number of growth rings. The Committee has obtained considerable information on this subject, but the problem is such a complex one that we do not feel ready to recommend any definite number of rings per inch for either pine or fir. It is anticipated that some conclusions acceptable to both consumer and manufacturer will be reached during the coming year.

With reference to the differentiation of the Southern pines, one of the members of the Committee says: "It is clear that the percentage of summer wood furnishes the only reliable quality of distinction, and that this is not always in proportion to the number of rings." He admits "the great simplicity in using the count of rings per inch, which also in most cases indicates the summer-wood percentage; but in order to avoid improper rejections I would add some such phrase as 'unless measurement of the summer wood show at least such and such per cent.'"

Referring to Mr. Elzner's reference last year to drop altogether the names longleaf, shortleaf, and loblolly, he desires that this suggestion be made again, and Dr. Fernow agrees with this

recommendation. Mr. Elzner also suggests the desirability of considering the question of shrinkage, which the Committee will take up during the coming year.

Mr. Nelson, who represents the yellow pine industry on the Committee, doubts the possibility of being able to distinguish longleaf, shortleaf, and loblolly pine by the number of annual rings. He suggests that it will be more advisable to inspect timbers by investigating the locality in which the timbers grew, and suggests the desirability of having the Committee prepare maps illustrating the distribution of the various species of pine.

The Committee would appreciate an expression from the members of the Society with regard to their experience in determining the different classes of pine according to the number of rings per inch, and also with reference to the suggestion made by Mr. Elzner and indorsed by Dr. Fernow, that the specific names of the pines be dropped.

Mr. Robinson is considering a specification for yellow pine which makes fourteen growth rings the minimum. With reference to the specification for Oregon fir, he suggests that it will be desirable to omit all reference to the percentage of heart.

In conclusion, the Committee recommends that the proposed Standard Specifications for Yellow-Pine Bridge and Trestle Timbers as presented at the last annual meeting be submitted to letter ballot of the Society for adoption.

Respectfully submitted on behalf of the Committee,

HERMANN VON SCHRENK,
Chairman.

W. K. HATT,
Secretary.

NOTE.—The Specifications for Yellow-Pine Bridge and Trestle Timbers were adopted by letter ballot of the Society on September 1, 1910, and follow this report.—ED.

AMERICAN SOCIETY FOR TESTING MATERIALS

PHILADELPHIA, PA., U. S. A.

AFFILIATED WITH THE

INTERNATIONAL ASSOCIATION FOR TESTING MATERIALS.

STANDARD SPECIFICATIONS FOR YELLOW-PINE BRIDGE AND TRESTLE TIMBERS.

ADOPTED SEPTEMBER 1, 1910.

(To be applied to single sticks and not to composite members.)

GENERAL REQUIREMENTS.

Except as noted, all timber shall be sound, sawed to standard size, square-edged and straight; shall be close-grained and free from defects, such as injurious ring shakes and cross grain, unsound or loose knots, knots in groups, decay, or other defects that will materially impair its strength.

Standard Size of Sawed Timber.—Rough timbers sawed to standard size shall mean that they shall not be over $\frac{1}{4}$ in. scant from the actual size specified. For instance, a 12 by 12-in. timber shall measure not less than $11\frac{3}{4}$ by $11\frac{3}{4}$ ins.

Standard Dressing of Sawed Timber.—Standard dressing shall mean that not more than $\frac{1}{4}$ in. shall be allowed for dressing each surface. For instance, a 12 by 12-in. timber after being dressed on four sides shall measure not less than $11\frac{1}{2}$ by $11\frac{1}{2}$ ins.

STRINGERS.

Standard Heart Grade. Longleaf Yellow Pine.—Shall show not less than 85 per cent. heart on the girth anywhere in the length of the piece; provided, however, that if the maximum amount of

sap is shown on either narrow face of the stringer, the average depth of sap shall not exceed ½ in. Knots greater than 1½ ins. in diameter shall not be permitted at any section within 4 ins. of the edge of the piece; but knots shall in no case exceed 4 ins. in their largest diameter.

Standard Grade. Longleaf and Shortleaf Yellow Pine.—Shall be square-cornered, with the exception of 1 in. wane on one corner. Knots shall not exceed in their largest diameter one-fourth the width of the face of the stick in which they occur, and shall in no case exceed 4 ins. Ring shakes shall not extend over one-eighth of the length of the piece.

CAPS AND SILLS.

Standard Heart Grade. Longleaf Yellow Pine.—Shall show not less than 85 per cent. heart on each of the four sides, measured across the sides anywhere in the length of the piece, and shal be free from knots over 2½ ins. in diameter.

Standard Grade. Longleaf and Shortleaf Yellow Pine.—Shall be square-cornered, with the exception of 1 in. wane on one corner, or ½ in. wane on two corners. Knots shall not exceed in their largest diameter one-fourth the width of the face of the stick in which they occur, and shall in no case exceed 4 ins. Ring shakes shall not extend over one-eighth of the length of the piece.

POSTS.

Standard Heart Grade. Longleaf Yellow Pine.—Shall show not less than 75 per cent. heart on each of the four faces, measured across the sides anywhere in the length of the piece, and shall be free from knots over 2½ ins. in diameter.

Standard Grade. Longleaf and Shortleaf Yellow Pine.—Shall be square-cornered, with the exception of 1 in. wane on one corner, or ½ in. wane on two corners. Knots must not exceed in their largest diameter one-fourth the width of the face of the stick in which they occur, and shall in no case exceed 4 ins. Ring shakes shall not extend over one-eighth of the length of the piece.

LONGITUDINAL STRUTS AND GIRTS.

Standard Heart Grade. Longleaf Yellow Pine.—One side shall show all heart, and the other side shall show not less than

85 per cent. heart, measured across the side anywhere in the length of the piece; shall be free from any large knots or other defects that will materially injure its strength.

Standard Grade. Longleaf and Shortleaf Yellow Pine.—Shall be square-edged and sound, and shall be free from any large knots or other defects that will materially injure its strength.

LONGITUDINAL X-BRACES, SASH BRACES AND SWAY BRACES.

Standard Heart Grade. Longleaf Yellow Pine.—Shall show four square corners and not less than 80 per cent. heart on each of two faces, and shall be free from any large knots or other defects that will materially injure its strength.

Standard Grade. Longleaf and Shortleaf Yellow Pine.—Shall be square-cornered and sound, and shall be free from any large knots or other defects that will materially injure its strength.

TIES AND GUARD RAILS.

Standard Heart Grade. Longleaf Yellow Pine.—Shall show one side all heart; the other side and two edges shall show not less than 75 per cent. heart, measured across the face anywhere in the length of the piece. Shall be free from any large knots or other defects that will materially injure its strength. Where surfaced, the remaining rough face shall show all heart.

REPORT OF COMMITTEE D-8 ON WATERPROOFING MATERIALS.

During the past year the work of Sub-Committee A, in charge of the investigation of waterproofing methods through the incorporation of foreign substances in mortars and concretes, has consisted principally of a careful study of the test results on which were based the broad conclusions intimated in the last annual report. These conclusions have been reinforced by test results at longer periods than were originally available, and further strengthened by the repetition of certain investigations to check the original findings. While a large number of tests on as many as forty or fifty waterproofing compounds have been independently made by several members of the Committee, this number does not include all the materials exploited from time to time, for they are of mushroom growth. The complete tabulation of tests on the materials examined is not presented in this report; nor is it considered necessary, since it is very doubtful whether the general personnel of the Society would be interested in anything but the deductions that the Committee now presents, and which are in line with all previous reports.

While it is admitted that laboratory methods for the study of this class of materials are necessarily somewhat different from the practical application of the material on a large scale, and that the manufacturers might question positive conclusions from the former, as not indicative in every case of behavior in the field, because the results of different laboratory examinations are not absolutely concordant; nevertheless, in the opinion of the Committee, several facts are established from such examinations, viz:

1. That the general effect of these incorporated foreign compounds is to reduce the tensile strength of mortars. This refers to a general reduction in the strength of mortars carrying these so-called incorporated waterproofing admixtures, when compared with standard untreated mortars.

2. That resistance to water penetration in mortars and concretes, being essentially dependent upon the density of such materials, can so easily be assured through proper proportioning

of the normal ingredients (all other conditions of handling and placing being normal), that no addition of any foreign substance is absolutely necessary.

3. That when, through lack of proper volumetric proportioning in the aggregate (sand in mortar or sand and stone in concrete), some extraneous material is needed to insure filling the voids, this can be accomplished by the use of natural materials, such as colloidal clays or hydrated limes, and practically perfect results obtained without resorting to the use of proprietary materials, whose general effect is to reduce the strength with no marked improvement, as a rule, in water-resisting characteristics. Investigations to date do not show that the effect of any of the admixtures is other than mechanical.

The Committee therefore concludes that it has accomplished for this class of materials, namely, incorporated admixtures, all that is possible under present conditions of laboratory examination. If funds and time had been available to inaugurate extensive tests under field conditions, some apparent value, shown in individual laboratory cases, particularly at early stages in two or three out of the forty or fifty examined, might have been emphasized under field conditions, either of crude workmanship with good natural materials, or the best workmanship with poor natural materials. But, as it is an admitted fact that theoretically waterproof mortars and concretes can be secured by proper proportioning, proper mixing, and proper handling of their ingredients,—and this has been repeatedly accomplished in practice under proper organization and supervision, without the use of any admixtures of so-called waterproofing materials, and can in any case be secured, even with poor natural materials, by the addition of similar natural material,—it appears that the claim of waterproofing characteristics advanced for most of the proprietary materials examined cannot be substantiated by any laboratory tests so far developed.

Sub-Committee B, in charge of the investigation of waterproofing methods through the use of bituminous materials applied directly to the surface to be treated, or through cloth or similar mediums, has inaugurated a series of tests, as briefly outlined in last year's report. The concrete tanks were protected by six different proprietary materials or methods of protective coating, and then subjected to the influence of four different liquids, as

previously described. The tanks have been regularly inspected and records kept. Several have failed, but as a final examination has not yet been made, no further report can now be presented.

Respectfully submitted on behalf of the Committee,

W. A. AIKEN,
Chairman.

A. W. DOW,
Secretary.

DISCUSSION.

Mr. Cyril de Wyrall.—The main object in waterproofing subterraneous structures is to keep them dry, or at least free from excessive moisture. Especially is this necessary where electricity is used as a motive power, and where electrically operated signals are depended upon for the safety of trains and their human freight. Water of itself, in very slight quantity, will short circuit and disarrange the signal operation, causing a delay of traffic with the resulting inconvenience; and when there is added the steel and iron dust which comes from brake shoes, etc., the danger from this source is multiplied. **Mr. de Wyrall.**

The damage caused by electrolysis is increased considerably where excessive moisture occurs, and considering further the danger from slippery rails, it can readily be seen that efficient waterproofing is very essential to the proper operation of subways. These points seem frequently to escape the notice of engineers who design structures and write specifications for their construction. For some reason they do not deem it necessary to profit by the experience with works already built, as shown by their adherence to bad precedents.

The greatest disintegrators of asphaltum and pitch bitumens, which are mainly used for waterproofing, are benzol, or gas drip, kerosene or petroleum and other like oils, and ferrous hydroxite. The latter substance is a seepage which is peculiar to gneiss rock formation, such as is found on Manhattan Island. These well-known foes of bitumens should be particularly guarded against, and yet the specifications for the first New York subway called for a bitumen or pitch of which 95 per cent. should be soluble in naphtha. There was some excuse for this, since, in the absence of precedent, it was thought that with a protection of concrete over the waterproofing layer, the latter would prove efficient for all time. In connection with the asphalt, a felt was used as a binder, in from two to six layers, as was found expedient. Hot brick and asphalt were also used in several places, all of which have failed in places where it was most necessary that this should not have occurred.

Mr. de Wyrall. Where water has not touched the waterproofing, it has, as a rule, held good; but where water has come into actual contact with the waterproofing, it has failed. Where the water has been impregnated with benzol or gas drip, due to leaking gas mains, it has gone through the protecting coat of concrete, and in numerous instances it has so dissolved the bitumen as to cause it to run through the shrinkage cracks between the concrete and the steel, and to drip through on the platforms and tracks. When an excavation was made to repair the waterproofing at some of these points, there was practically nothing left; everything had been dissolved. In short, the waterproofing generally has proved efficient, provided the water had been kept away from it.

Having all these facts, and nearly eight years of experience to profit by, practically the same specifications are again placed in the hands of contractors to bid on, for the new subways. While engineers very properly insist on certain formulas of mix, or aggregate, on a certain thickness of concrete, on tests of cements, stone and sand, and other materials; yet for a material necessary to keep out water, on which, in many instances, depends the life of these other materials, no tests are deemed necessary; or, if demanded, they are usually conducted on lines diametrically opposite to those on which they should be.

During the past six years no repairs have been necessary to the concrete or steel of the present New York subway, but thousands of dollars have been spent in repairing the damage done by inefficient waterproofing materials. The train service has been put out of commission through water dropping on signals; cables have been blown out, and the telephone service has been crippled from the same cause. When it is considered what a ten-minute delay in traffic in a subway carrying nearly one million people every twenty-four hours means, it seems that some closer attention should be given to keeping such a structure dry.

Aside from gas drip and oils, the failure of hot brick and asphalt is due to air bubbles in the joints. As these form an outer shell, they are not perceived until the pressure bursts the shell and the damage is done. Again, the brick may not have been thoroughly dry originally, in which case the skin formed by the hot asphalt will eventually give way, the bond between it and the brick being insufficient, due to the presence of moisture in the brick.

Mr. de Wyrall.

The failure of felt binder is due to the fact, that when water once gets to these binders, they become spongy and rot away. The writer has taken a handful of such material, and squeezed water out of it as though it were a sponge, and that in localities where considerable excavation had to be done in order to get a proper lap on the old material.

To get an efficient waterproofing material, the chemical tests specified should be radically changed. A carbon test by heating should be required, and a bitumen should be demanded of which at least 30 per cent. should be insoluble in cold naphtha. The running and melting points are much too low. It is folly to specify a bitumen that will run at 60° and melt at 100° F., as it would be impossible to keep it on a vertical wall at a summer temperature such as obtains in this latitude, unless it were nailed on, especially with four- or five-ply work. A far better specification would be, that bitumen should have a melting point of not less than 200° F. and that it should be pliable at 20° F.

The use of felt should not be permitted, and a closely-woven fabric should be used instead, for the following reasons:

First: Because of its greater strength.

Second: If a puncture occurs where a fabric is used, the leak will appear at or very near that point; but with a felt, owing to the layers, the water will have to travel several feet before it gets through to the concrete, which causes considerable expense for excavation in locating the sources of leaks. The writer has gone as far as sixty feet to locate trouble. This is very expensive, especially where the streets are paved with asphalt.

Third: Two plies of good fabric will meet the requirements in nearly all cases.

It has been suggested that waterproofing is unnecessary in subways except at stations. This is a grave mistake, and would prove a very expensive one to the operating company, which has to maintain the structure and make good any damage by water. The cable ducts run between the stations, usually as part of the structure, and it is essential that they should be kept dry. A high-voltage cable blow-out is dangerous and costly, and these blow-outs are caused more frequently by water than anything else.

Another suggestion that has been offered is to waterproof the sides to the ground-water level. This plan is also inefficient, since

Mr. de Wyrall. most of the trouble occurs in the roof, and is caused by leaking house-service water pipes and joints in mains. Such leaks, together with the gas, and the oil from the street railway switches, are a source of considerable expense, especially near a signal or over contact rails. The writer knows of several instances where shocks have been received by workmen standing near a point at which water dripped from above the contact rail, although the rail was protected by a board.

It has also been suggested that some mixture should be added to the concrete aggregate, as a waterproofing medium. The result of this method will depend on whether a structure can be constructed without developing shrinkage or temperature cracks, and on whether an ideal mixture can always be obtained. As the coefficient of expansion of concrete is well known, and as temperature changes of 70° F. occur in the present subway, the success of this method of waterproofing has yet to be demonstrated.

If a subway line could be constructed in streets or avenues where no water and gas mains or street-railway tracks exist, and where the material is sand or gravel, and is above ground-water level, it would be unnecessary then to use any waterproofing whatever. But as subway lines are generally located in the busiest city districts and the evils mentioned are always present, it is a serious mistake not to guard against them, especially since the cost of waterproofing is only a small percentage of the total cost, and since experience has taught that it is imperatively necessary to keep subways dry.

THE WELDING OF BLOWHOLES IN STEEL.

By Henry M. Howe.

The investigation on which this paper is based was made under a grant from the Carnegie Institution of Washington.

1. The present paper gives evidence tending to show that the sides of blowholes may, in rolling, be welded together to a great

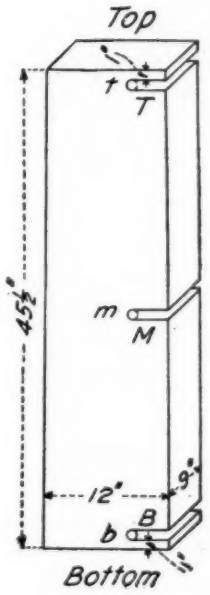

Fig. 1.

extent. This, together with the evidence I have already given and the antecedent probabilities in the case, lead me to infer that, under favoring conditions, this welding may be complete, so that the blowholes not only disappear but cease to exist.

In a previous paper* I showed that the great initial difference

*"The Closing of Blowholes in Steel Ingots." *Proceedings*, 1909, Vol. IX, pp. 327 ff.

in density between the porous and the compact parts of a boiler-plate ingot made by the Lukens Iron and Steel Company in one case completely disappeared in rolling that ingot down into a plate, and in a second case was reduced from 10 per cent. to 0.2 per cent., or to one-fiftieth of its initial quantity. In view of the great ease with which gas is known to pass into and out of solid iron under other conditions, this fact, that the rolling had

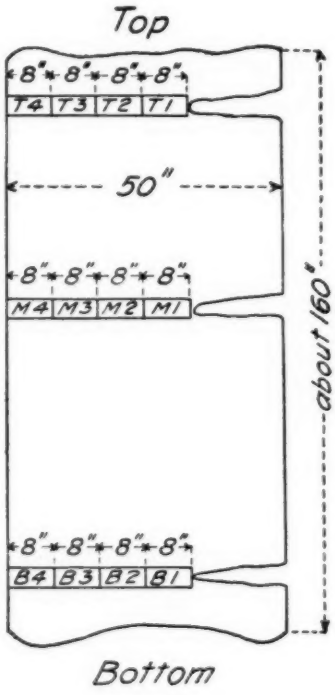

FIG. 2.

made the initially porous parts practically as dense as the initially compact parts, seemed strong evidence that the rolling had actually caused most of the initial gas to disappear; in short, had expelled it in the sense of making it cease to exist as gas within the metal.

2. I promised further evidence based on a microscopic examination of the boiler plate, and hinted that I might answer the further question, "If the blowholes can be closed, can they be

welded?" This evidence I will now give. It consists of the number, size, and appearance of the detectable traces of blowholes in polished sections of the boiler plate, and in polished slices cut from that plate and bent over in a way which ought to cause any such traces to yawn open and become conspicuous.

3. Fig. 8* shows how these slices were taken, and helps us to interpret the traces of blowholes which we find in them. You will remember that three slabs, *T*, *M*, and *B*, Fig. 1, were cut from the right-hand side of a boiler-plate ingot; that this ingot

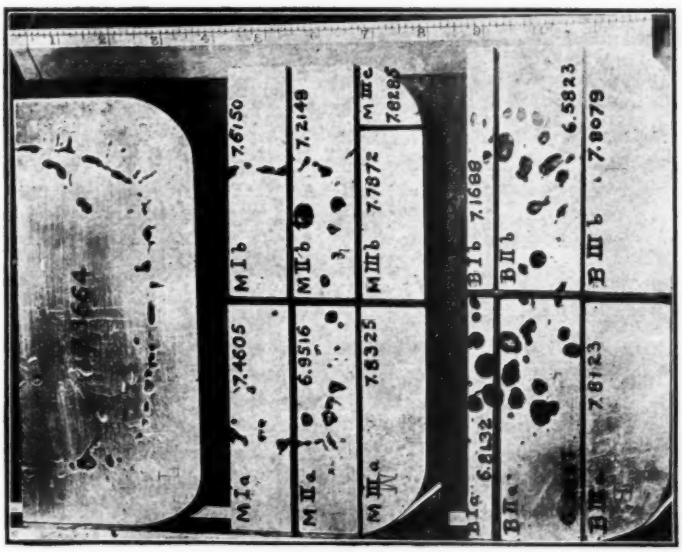

FIG. 3.—The three ingot slabs, showing how they were cut up for density determinations, and their specific gravity.

was then rolled down into a plate; and that strips $T1$ to $T4$, $M1$ to $M4$, and $B1$ to $B4$ were cut from this plate opposite where the ingot slabs had been cut (see Fig. 2). I assume that the metal now in these plate strips $T3$, $T4$, $M3$, $M4$, $B3$, and $B4$, contained, when it was in the ingot and before rolling began, blowholes substantially like those which exist in the corresponding ingot

* This paper and the previous one form really the closely connected parts of a single whole. Hence I have numbered the figures and tables of this present paper so that they follow on after those of the previous paper, beginning with Fig. 8 and Table IV.

slabs, as shown in Fig. 3. In Fig. 8 the square prism *BIa-BIb* shows the blowholes in a certain part of one of those ingot slabs as shown in Fig. 3, and the square collar I, II, III, IV, shows the corresponding metal from the left side of the ingot after rolling down into a plate.

Thin slices, I, II, III, and IV, were cut from the edges of this square collar, mirror-polished, examined for traces of blowholes, then bent over as shown in Figs. 13, 14 and 16, and re-examined. The appearance of these slices under a lens seems to me a very

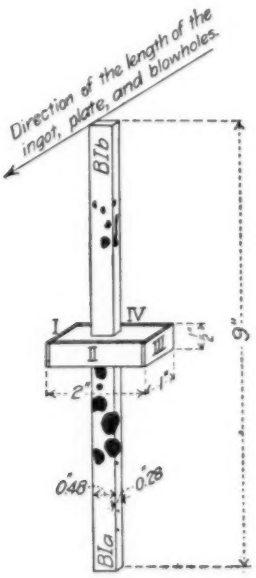

FIG. 8.

instructive object lesson. This method of testing I owe to Mr. J. P. Snow, who has found it effective in revealing in rail sections flaws which were invisible without this bending. The results of my observations are summed up in Table IV.

4. Let us now consider how the relics of the original blowholes ought to look when these little slices are thus bent, first in §§6 to 13, on the theory that no welding occurs, and then, in §§14 to 20, on the theory that there is more or less welding; remembering that, at the bottom of the ingot whence these slices come, the blow-

TABLE IV.—DEFECTS FOUND IN MIRROR-POLISHED SLICES I, II, III, AND IV, ON BENDING.

Slice No.	Designation letter.	Number of Defects.	Length, ins.	Width, ins.	Shown in Figure No.	Straight-walled (S) or with Gas Bubble (G)	Remarks.
I.	*a*	1	0.04	0.002	15	S	
"	...	about 12 in line with *a*	0.002 to 0.012	about 0.002	....	S	Total length over all including *a*, 0.3 in.
"	*b*	2 tandem	0.002 to 0.005	0.001	16	S	Total length over all, 0.03 in.
II.	*c*	1	0.07	0.01	13	G	
"	*d*	1	0.06	0.01	13	S	
"	....	5	0.02 to 0.04	0.01 to 0.02	...	G	
"	....	2	0.02 to 0.04	0.002 to 0.005	...	S	
III.	....	2	0.005 to 0.01	0.002 to 0.01	...	G	
"	....	1	0.008	0.002	....	S	
IV.	*e*	1	0.05	0.02	14	G	
"	*f*	1	0.02	0.008	....	G	In line. Length over all, 0.07 in.
"	*g*	1	0.02	0.008	....	S	
"	....	7	0.001 to 0.01	0.001 to 0.005	...	G	
"	....	2	0.003 to 0.01	0.002	....	S	
"	....	2	0.001 to 0.005	0.001 to 0.002	...	?	

holes are initially sausage-shaped, with their axes nearly vertical, more than 1 in. long (but how much more we do not know), and about $\frac{1}{3}$ in. in diameter. Then let us see in §21 what the actual appearance of the bent slices is; in §§22 and 23 with which theory it agrees the more readily; and in §§24 to 27 let us look at some considerations related to this general subject.

Let us remember that the closing of the blowholes and the welding of their sides are two distinct things. Closing a blowhole, like closing a door, merely means bringing two surfaces into contact; it does not imply sticking them together. Of course complete effacement of blowholes implies both complete elimination of gas and the consequent complete closing of the gas bubbles; and further the complete welding together of the walls of the

blowholes which have thus been closed together. The complete elimination of the gas, to which the density determination of my previous paper pointed, does not in the least imply the welding together of the closed walls, though the complete welding of the whole of the walls would of course imply the complete elimination of the initial gas. Yet partial welding need not necessarily imply any elimination of gas at all, because the partial contact necessary to that partial welding may be due to the compression of the gas rather than to its elimination.

The question to which the following discussion is primarily addressed is, "How far, if at all, are the walls of the blowholes welded together?" or, in other words, "Are the blowhole-walls qualitatively weldable?" But, as we shall see, the evidence actually throws much light on the other question, "Is the gas qualitatively eliminable?"

5. *Definitions.*—By "*Relic*" I mean all that remains of the original blowhole. These remains may include a "Gas-bubble" and a "Tail."

A "*Gas-bubble*" evidently is whatever gas remains uneliminated.

A "*Tail*" means the parts of the original blowhole which have been folded flat together, and remain in contact with each other, but have not been welded.

By the "*Elimination*" of the gas, I refer to its ceasing to exist as gas within the gas-bubble, whether because of re-absorption or of any other method of removal. Re-absorption seems to me personally to be the natural and probable method of removal.

By the "*Volume*" of the gas-bubble I refer always, unless I clearly indicate the contrary, as in §6, to the volume between passes, and not to the volume while immediately under the pressure of the rolls. Between passes, when this direct pressure has ceased, there will be more or less re-expansion, governed, first, by the mass of gas and its temperature, and second, by the resistance offered by the enclosing metal to re-expansion. In any event this resistance will increase as the metal stiffens with the progress of cooling, but welding would further increase it very greatly, by eliminating the tails which, in the absence of welding, can be opened up by the pressure of the gas.

6. *What Relic Should a Blowhole Leave if there is no Welding?*—Fig. 9 shows my idea of the successive shapes which a given relic should assume in the first pass. The compression and hence the lengthening take place in chief part very soon after the rolls have gripped the ingot, and when the vertical component of the motion of their surface is large. By the time that the metal has

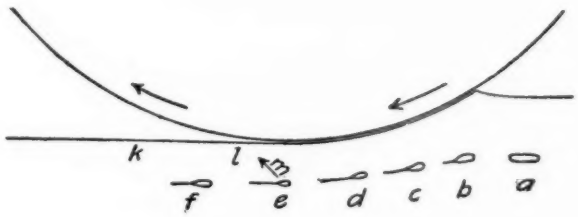

FIG. 9.

approached the vertical plane passing through the axes of the rolls, the vertical component of their motion has become insignificant, and though the intensity of the pressure probably increases continuously up to this point, their "work" proper here consists chiefly in dragging the metal forward and compelling the parts of the metal behind to submit to the strong compression which accompanies and immediately follows their entrance into the

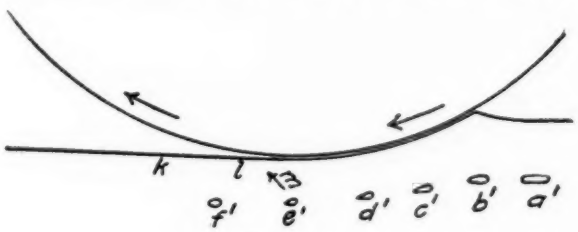

FIG. 10.

rolls. Hence the rapid lengthening of the relic, taken as a whole, between positions *a* and *c*, and its slight lengthening between positions *c* and *e*.

The continuity of the vertical reduction between *a* and *d*, in spite of the fact that the rate at which that reduction goes on is continuously retarded, implies not only a continuously increasing pressure on the bubble and hence a corresponding decrease in

its volume, but also that in any given position in this range the "bow" as it were of the bubble is under greater pressure than its "stern." I should expect that this fact, that the pressure is greater forward than aft, would first turn each relic into a thin flat "pear," as at *b*,—thus giving it two distinct parts, a closed flat "tail," and a gas-bubble which forms the body of the pear—and would then progressively lengthen the tail of that pear, i. e., that part of its forward end which has closed down tight, and that at the same time the volume of the bubble would decrease. Between positions *d* and *e* there should be little lengthening, and little more than a further reduction of the volume of the bubble. But the moment the bubble passes beyond position *e*, and the gas in its forward end ceases to be under direct vertical pressure, while that in the rear remains under that pressure, the bubble should tend to expand forward. This forward tendency should continue till the rear end of the bubble has passed the axial plane of the rolls. Indeed, even in position *e* the bubble may begin to expand forward, because the upper surface of the metal between *k* and *l* is under no pressure from the rolls, and the pressure of the gas might relieve itself by forcing the overlying metal in the direction of the arrow *m*. The volume of the bubble at *f* should be much less than its initial volume, not so much because the temperature is now below that at which it originally formed in the solidification of the ingot, as because the stiffness of the enclosing metal retains the gas under very considerable pressure, certainly under a pressure far in excess of that which existed during the solidification of the ingot. If there is re-absorption, that would further lessen the volume of the bubble. This same stiffness should prevent the re-opening of the tail at *f* from reaching or even closely approaching the forward end of the relic.

No further change in the relic need be expected until the next pass, which should shift the bubble back to the left or present rear end (*n*, Fig. 11), and further lessen the volume which it reaches on expanding after passing the axial plane, because of the further cooling and stiffening of the enclosing metal. And so on pass after pass, the bubble should decrease in volume, and should shift back and forth from end to end of the flat-folded but unwelded remains of the initial cavity. Thus the original blowhole becomes reduced to the shape of a long-tailed pear. The tail is simply a

CONJECTURED SIZE AND SHAPE OF RELICS OF BLOWHOLES AT SEVERAL STAGES IN ROLLING A BOILER PLATE INGOT.
FIRST APPROXIMATION.

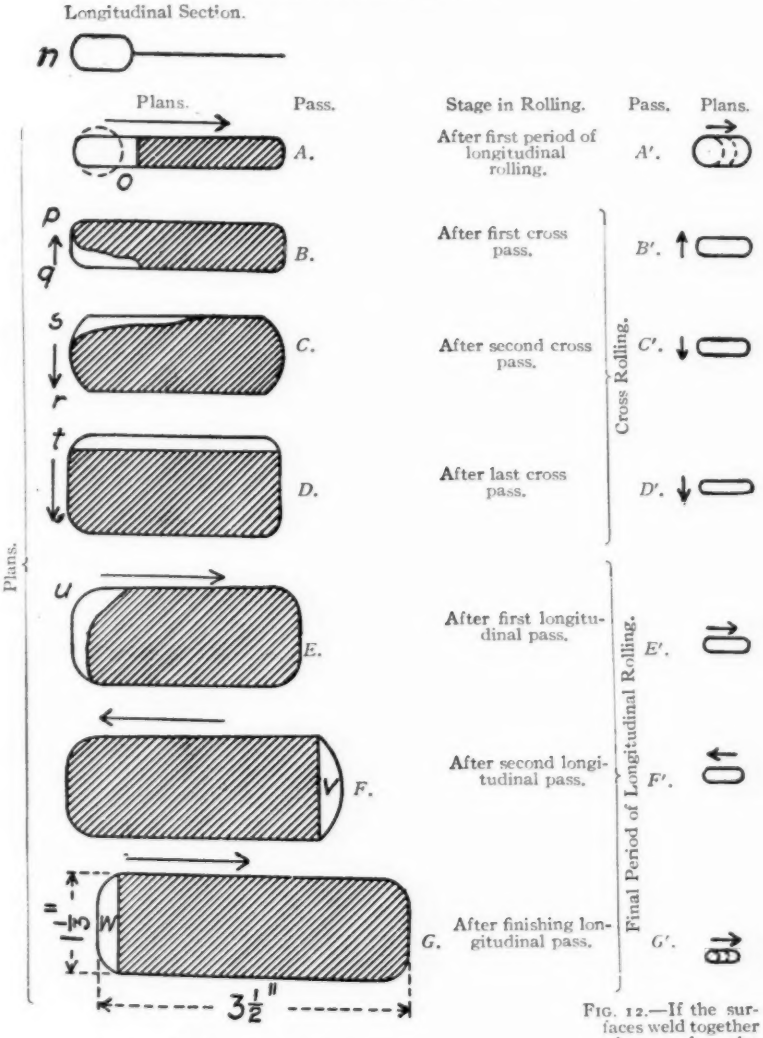

FIG. 11.—If there is no welding.

FIG. 12.—If the surfaces weld together wherever brought into contact with each other.

LEGEND: The hatching represents surfaces closed together, but not welded. Arrows indicate direction in which the piece moves in the pass in question.

plane of contact, unwelded by assumption, and the gas-bubble or pear represents the initial gas, which, even if it were assumed to remain constant in quantity, must needs be ever lessening in volume from pass to pass, because of the falling temperature, and more especially because of the increasing pressure due to the increasing stiffness of the metal. But, because there has been little widening of the piece parallel with the axes of the rolls, the relics of the blowhole should retain approximately its original width, and its plan should be something like that sketched at *o*, Fig. 11. The hatched parts in Fig. 11 represent the unwelded part or "tail" of the blowhole.

7. If the piece is now turned 90°, after its first cross-rolling pass the relic should look something like *B*, Fig. 11,—i. e., taking it as a whole, bubble plus tail, it should be slightly widened in the direction of the arrow, and its bubble should be shifted to what has now become the rear side. But, as here sketched, the bubble need not reach clear across this rear side, because when it has expanded to a shape something like that here shown at *q*, the pressure of the gas within it may have fallen so low that it cannot further re-open the now stiff metal. After the next cross pass, the relic should look something like *C*, in plan, with a narrow gas-bubble, *s*, at what has now become its rear side.

In each of the following cross passes the approach of the pressure of the rolls should force the gas bubble back from the forward side of the relic of the blowhole, so that it re-opens and forces apart the flat-folded but unwelded tail here hatched, and so travels across to what for that pass is the rear side of the relic. And each time that it thus traverses the unwelded but flat closed tail, the gas-bubble should spread out in such a way as to stretch along a greater proportion of the rear side than it covered at the end of the preceding pass; for example, so that it is longer and narrower in *C* than in *B* of Fig. 11, till it soon extends the whole length of the rear side, as at *t*.

8. Because the slab or plate does not lengthen materially, but only widens, during the cross passes, the relic of the blowhole should not lengthen, but should gradually widen, as shown in the successive stages *B*, *C*, and *D*.

9. In the following longitudinal pass, *E*, the bubble shifts back from what was the rear side in the last preceding pass, *D*, to

what is the rear end in this present pass, as shown at *u*. Because of the resistance of the closed walls to being re-opened, instead of lying evenly across the end of the relic it would lie somewhat diagonally as sketched at *u*. In the next pass, *F*, besides shifting back to what is now the rear end of the relic, it lies less diagonally and more nearly across the end as shown at *V*. And so on to the final pass *G*.

10. So much for the shape of the bubble; now for its area.

Even if, for simplicity, we ignore the probable elimination of gas, there should be a very material progressive decrease in the volume of the bubble, partly because of the fall of temperature, which might well lead to a loss of some 35 per cent. in volume, and partly because of the progressive increase in pressure under which the gas is held, due to the increasing stiffness of the enclosing metal. As a very rough guess let us say that the volume of the gas-bubble is reduced by half. But along with this decrease goes a very great thinning of the plate, to one-eighteenth of the thickness of the ingot, and this thinning of the plate should tend to cause a marked thinning and hence widening of the bubble. If half the volume of gas is spread out in a layer one-eighteenth as thick as the initial layer, the area of that layer in plan would be nine times the initial area in plan. I might have represented this by a progressive increase in the area of the bubble in Fig. 11.

If, now, the progressive elimination of the gas—which we have every reason to expect—is taken into account, this would progressively decrease the area of the bubble as it appears in our plans *A* to *G* of Fig. 11, and, if complete, as it might well be, would lead to the complete disappearance of the bubble. As it is clearly impossible to form any quantitative estimate of the net result of these several causes, I have made the area of the bubble the same in the several stages shown in Fig. 11, which after all is only diagrammatic.

But it is very important for our diagnosis to recognize that, be the final area of the bubble greater or be it less than sketched in *G* of Fig. 11, the bubble should stretch across the relic of the blowhole, for this is the position which it would naturally take when the pressure of the last pass drove it from the front to the rear end of the relic, between the unwelded walls of the tail. Further, the more thorough the elimination of the gas the more should these residual bubbles approach the form of a thread.

In the foregoing I have made no attempt to follow with exactness the progressive shrinking of the bubble and lengthening of the tail. In particular, I have for simplicity left out of sight the cornerwise rolling which habitually comes between the early lengthwise passes and the cross rolling. Without going farther into the matter, it seems very probable that, on our present assumption that no welding occurs, the relic of any given initial blowhole must soon assume and must henceforth keep the shape of a long narrow gas-bubble, with a broad, flat, closed, but unwelded tail; further, that the length of this bubble must lie crosswise of the finished plate.

11. In passing from its original sausage shape to this, the relic should lengthen and widen with the enclosing metal. If we take the initial length and diameter of a given blowhole as something more than 1 in. and about $\frac{1}{3}$ in. respectively, then, because the ingot is drawn out to 3.5 times its initial length and widened to 4.17 times its initial width, the remains of such an initial blowhole should be something over 3.5 ins. long, about 1.4 ins. wide, with a narrow bubble at its rear end, running crosswise of the plate, as at *W* after the final pass *G*, Fig. 11.

This is on the assumption that the pressure of the gas against the rear end of the bubble in such positions as *c*, *d*, and *e*, Fig. 9, will never cause any ripping open of the rear end of the bubble, beyond the individual particles which initially formed the surface of its rear wall. If there were any such ripping open, on our present theory of non-welding this would necessarily lengthen and widen the relics of the blowholes proportionally, because the prolongation caused by this ripping must, on our present assumption, persist unwelded. In short, the length of 3.5 ins. and width of 1.4 ins. of these relics of blowholes are the minimum dimensions to be expected on the theory of non-welding.

12. *Bulging.*—We might at first suppose that the gas-bubbles would be widened more than the tail, somewhat as sketched in dotted lines in *o*, Fig. 11. As the metal passes forward between the rolls, the gas in the forward end of the bubble is driven forcibly back, and this might be thought to make it bulge out sidewise somewhat, as here sketched. Direct observation alone can decide this. Personally I do not look for any such bulging, for a simple reason. We know as a matter of common observation that, in a length-

wise pass, the boiler-plate slab is not materially widened. This being true, it means that, if the space which in our relic is occupied by a gas-bubble were occupied by solid metal, that solid metal would not bulge out sidewise as sketched in the dotted lines. Of course such solid metal tries to bulge out sidewise, but its effort is completely foiled by the resistance of the surrounding solid metal. Now if the surrounding solid metal is able thus to prevent any bulging of imaginary solid metal occupying the volume which in our case is actually occupied by the gas-bubble, why is not that surrounding solid metal equally able to prevent the bulging out of the gas-bubble? Why should a bubble of gas be able to cause a bulging sidewise which a mass of solid metal of exactly the same dimensions cannot cause?

13. *How Should these Relics Appear in the Bent Slices?*—Each of these unwelded relics of an initial blowhole ought to lie in a plane parallel with the main surfaces of the plate, like the thin air-spaces that separate the cards of a pack, and they should cut across the thickness of each of these little slices I, II, III, and IV, Fig. 8, and crop out on its face. Hence when any one of these slices is bent, as shown in Figs. 13. 14, and 16, these relics of blowholes ought to gape open like the cards of a bent pack, revealing themselves as deep crevices, stretching along the face of the bent slice and usually penetrating right through from face to rear. In slices I and III, the faces of which are parallel with the length of the plate, these unwelded crevices should be at least 3.5 ins. long. In slices II and IV, the faces of which are parallel with the width of the plate, these crevices should be about 1.4 ins. long. (§ 11.) Further, because the gas-bubbles should be reduced to long narrow or even thread-like cavities stretching transversely in the finished plate (Fig. 11), many more gas-bubbles should be cut by the longitudinal slices I and III than by the transverse ones II and IV.

14. *What Relic Should a Blowhole Leave if there is Welding?*—Up to this point we have assumed that the opposite sides of blowholes, when forced together under the pressure of the rolls, remain unwelded, giving rise to the tails shown in Figs. 9 and 11, and to the partial re-opening of this tail, as shown at *f*, when the blowhole passes beyond the axial plane of the rolls. But, if these surfaces actually do weld as far and as fast as they are pressed into actual contact with each other, this welding should completely prevent

the formation of tails. The successive course of events should be somewhat as sketched in Figs. 10 and 12.

In the first pass, Fig. 10, the bubble should behave, between stages a' and e', exactly as if there were no welding, i. e., exactly as in Fig. 9. But the absence of any tail should prevent the slight re-expansion of the blowhole which on the non-welding theory occurs between stages e and f, because that re-expansion is due to the slight re-opening of the unwelded tail. Hence the bubble at stage f' would be slightly smaller in case there is welding than in case there is none.

15. *Is the Compression of the Bubble Due to Welding Cumulative?*—We have next to ask whether this difference is cumulative, being added to pass by pass, so that at the end of the rolling a very marked decrease in the size of the bubble will have been caused by welding. It appears to me that this difference would be cumulative if the gas is qualitatively eliminable, but not if it is not eliminable, as I will now explain. To fix our ideas let us follow the course of bubble f (Fig. 9) of the non-welding theory, and of bubble f' (Fig. 10) of the welding theory.

16. *If the Gas is not Eliminable*, then, in the second pass, the dimensions to which bubble f' will be reduced will be the same as those to which bubble f will, because this volume depends solely on the pressure put on the bubble in that pass and retained on it by the stiffness of the surrounding metal after the pass, which pressure is independent of the volume of the bubble at the beginning of this pass.

This same stiffness tends to limit the pressure reached in the bubble, but both stiffness and pressure should be the same in one case as in the other. I believe that we may here safely neglect the fact that the pressure has each time to move the walls of the bubble a little farther on the non-welding than on the welding theory.

After the pressure of this second pass is removed, bubble f will re-open slightly, whereas bubble f' will not; but this simply re-establishes the difference which arose at the end of the first pass and does not add to it. And so on, pass by pass.

The effect of the progressive increase in gas pressure from pass to pass need not be considered, because it is balanced by the corresponding increase in the stiffness of the metal. Indeed the latter increase is the cause of the former.

17. *If the Gas is Eliminable*, then because bubble *f* re-opens slightly after each pass whereas bubble *f'* does not, the pressure of gas in *f'* will be higher than that in *f* during each and every interval between passes, i. e., during nearly the whole of the rolling process, because the time occupied by any given bubble in passing between the rolls is but an insignificant fraction of the whole time. Because the gas pressure is greater in *f'* than in *f*, the absorption of gas by the metal from the bubble will, in each interval between passes, be the greater in *f'*, and hence the quantity of gas remaining in *f'* will fall short of that in *f* by an amount which will increase successively from pass to pass, and so, for given temperature and pressure, will the volume of gas.

Now the elimination of the gas has been rendered extremely probable by the evidence in my prior paper, which showed that rolling practically eliminated the great difference in density which existed between the compact and the porous parts of the ingot. Hence we are justified in indicating in our sketches in Fig. 12, that the volume of the bubble on the welding theory falls progressively farther and farther short of that sketched in Fig. 11 for the non-welding theory.

18. *Shape of Bubble.*—Turning now from the volume to the shape of the gas-bubble, and remembering that the lengthwise passes may lengthen or shorten the bubble but cannot change its width materially; that the cross passes may narrow or widen the bubble but cannot materially change its length; and further, that the great change of volume and length will come in the first pass, when the great pressure of the rolls is substituted for the feeble pressure under which the blowhole formed initially; we may sketch the plan of the bubble *o'* at the end of the initial lengthwise rolling as at *A'* in Fig. 12. Here the width is made the same as at the same stage on the theory of non-welding, *A*, Fig. 11, because in both cases it is the same as the width of the initial blowhole; but the length of bubble *o'* is decidedly less than that of *o*, because of the cumulative excess of diminution of volume on the welding theory explained in § 17. For the reasons just given, in the cross passes *B'*, *C'*, and *D'*, the bubble narrows progressively without change of length, and in the final lengthwise passes it shortens progressively without change of width.

To what degree the bubble shortens in the first lengthwise

rolling of course depends on the rapidity of the elimination of gas, as to which we have no direct information. The bubble may be shorter than I have here sketched, so that its forward end would be represented by one of the dotted lines shown in *A'* and *G'* of Fig. 12 instead of by the solid line.

19. *The Effect of Cross Rolling* is extremely important. In the absence of welding it widens the tail along with the plate, thus leaving a wide unwelded space across which the gas-bubble stretches in the subsequent longitudinal rolling, remaining as a long cylinder or even thread running across the plate, as at *G* after the last pass (§10). Welding, by preventing the formation of tails, greatly lessens the widening of the relic in cross rolling, holds the bubble more compact, certainly lessens its dimensions transverse to the plate, and very likely leaves it longer along than across the plate.

20. *How the Relics Should Look in the Bent Slices on the Theory of Total Welding of the Tails.*—There should be no unwelded seams to gape open, and the only remaining defects should be the bubbles of uneliminated gas. From §19 it follows that there need not be more but may be fewer of these bubbles cut and disclosed by the longitudinal than by the transverse slices.

21. *If the Welding of the Tails Occurs but is Incomplete*, the conditions should be intermediate between those which we have pictured for the theory of total non-welding on one hand and that of total welding of the tails on the other. The more thorough the welding the less important should the tails be, the less prominent should they be in the bent slices, and in particular the smaller should be the proportion of bubbles found on the lengthwise to those found on the transverse slices. But the number of unwelded seams might at first increase with the thoroughness of welding, because incomplete welding might easily break up a single great tail, 3.5 by 1.3 ins., into a number of small fragments.

22. *What the Relics Are*, after mirror-polishing and bending, may be seen in Figs. 13 to 16, which include the worst of the flaws in slices I, II, and IV. The remaining slice, III, a longitudinal one, is much freer from flaws than the three here shown. Figs. 13, 14, and 16 are magnified about $2\frac{3}{4}$ diameters. Where these slices are bent sharply the mirror-polish has changed into a matte

PLATE II.
PROC. AM. SOC. TEST. MATS.
VOL. X.
HOWE ON BLOWHOLES IN STEEL.

FIG. 13.
($\times 2\frac{3}{4}$.)

FIG. 14.
($\times 2\frac{3}{4}$.)

FIG. 15.
($\times 40$.)

FIG. 16.
($\times 2\frac{3}{4}$.)

surface. Fig. 15, magnified 40 diameters, shows the flaws in line with *a* in slice I. These flaws lie outside of the sharply bent region.

Many slight flaws yawn open when the polished slices are bent. Nearly all of these are very shallow. Many of them have relatively straight smooth sides, and hence seem to be unwelded fragments of the tails of blowholes. The most pronounced of these is flaw *a* shown in Fig. 15. It is about 0.04 in. long, and stands with others in a line of which the total length, including the welded gaps, is about 0.3 in.

Other flaws like *e* in Fig. 14 look like minute gas-bubbles, sometimes with a tail at one or both ends, though even these may possibly be nothing more than unwelded places which have gaped in such a way as to suggest gas-bubbles. In any event the total volume of these is extremely small.

The longest flaw of all, *c* in Fig. 13, is 0.07 in. long. Besides this there are six between 0.04 and 0.06 in. long, two 0.03 in. long, and seventeen between 0.005 and 0.025 in. long.

In general the several flaws seem to be wholly unrelated to each other. The only exceptions to this rule, so far as I have noticed, are the flaws in line with *a* in Fig. 15 already noted; the two flaws *b* in slice I, Fig. 16, and two flaws *f* and *g* in slice IV.

The direction of each flaw is parallel with the main surfaces of the plate. In some cases there seems to have been more or less tearing open of the ends of the flaw in the act of bending the polished slice, and this tearing in some cases varies slightly from true parallelism with the surface of the plate. But I have noticed no case of waving or undulation.

If, from among the defects revealed by the bending of these slices, one were to select those most favorable to the theory of non-welding, he would take those shown in Figs. 13 and 15. The great majority of the defects are either like those shown in Fig. 14 or those shown in Fig. 15.

23. *Inferences from this Evidence.*—That the welding has not been absolutely complete is indicated by the presence of minute, nearly straight flaws like those shown in Figs. 13 and 15. The questions whether any welding has occurred, and if so how much, remain.

The number of the defects throws little light on these ques-

tions, because, as pointed out in §21, the first effect of welding might easily be to convert a few large cavities into many small ones.

But the general appearance of the mirror-polished and bent slices, as shown in Figs. 13, 14, and 16, is very instructive. Whatever allowance we may make for the fact that only the bent part is in sharp focus in these pictures, and that the focus in the tangential parts of the slices is less sharp, the contrast between the very minute cavities in these two slices and the large ones in the original ingot as shown in Fig. 8, seems to me to argue more cogently than any words of mine can that a very large degree of welding has actually occurred. "Look here upon this picture, and on this."

The size of the individual flaws seems to me to indicate that there has been a large amount of welding. Thus, instead of the length of 3.5 ins. which, as pointed out in §11, we should expect in slices I and III on the non-welding theory, the longest flaw that I have there found (*a*, Fig. 15) is only 0.04 in. long, or 1 per cent. as long as non-welding would imply. Instead of the expected length of 1.4 ins. in slices II and IV, the greatest length I have there found is 0.07 in. (*c*, Fig. 13) or 5 per cent. of what non-welding would imply.

Now, whatever allowance we may make for error in the expected size of blowholes, the discrepancy between that expected size and the actual size is so great that I see no ready way of explaining it other than admitting extensive welding. The fact that some twelve small cavities stand within a line which, including the welded spaces in it, is 0.3 in. long, far from seeming to me evidence that there has been no welding, seems to me very strong evidence that there has been welding, and that the now solid places in this line were connecting parts of a single initial blowhole. The fact that this is the longest relic of a blowhole certainly suggests that it is derived from one of the larger initial blowholes. Putting together the facts (1) that, if these larger blowholes were wholly unwelded, the length of their relics should be more than 3.5 ins., and (2) that the length of this relic is only 0.3 in., including the extensive welded gaps within it, we infer that even in this the least effaced of the relics, the welding has probably been more than nine-tenths complete. The fact that with two exceptions (*b*, Fig. 16, and *f*-*g* in slice IV) no like relation can be traced between the other little flaws, seems to mean that, in these other cases, the

welding has been so much more than nine-tenths complete as to mask the connection between the vestiges of a given initial cavity. Looking at it in another way, the fact that certain flaws are in line with *a* and evidently are the relics of what was once a single blowhole, and the further fact that not only these but all other flaws and yawnings always lie in a plane parallel with the face of the boiler plate itself, tend to confirm our general conception of what the shape of the remains of the blowholes ought to be if there were no welding. But the absence of traceable relation between nearly all the other remains tends to show that these other blowholes have been welded up even more completely than that whence these related relics spring.

We might at first be tempted to explain the lack of relation or correspondence between the different little relics of blowholes by referring it to irregularities in the compression of the steel, which would move different fragments of a given blowhole into different planes, and thus hide their original relation to each other. That there should be such irregularities of movement might well be supposed. In the passage through the rolls, metal which lies in a horizontal plane either above or below that in which the blowholes lie, and is immediately over a partition wall which separates blowholes instead of being over the blowholes themselves, might be supposed to flow irregularly to right and left into the blowhole cavities themselves. Without passing on this question, let me point out that, were this irregularity of flow such as to move different fragments of a given blowhole into different planes, and thereby to conceal the relation which those fragments originally bore to each other, then it certainly ought at times, by like effect, to move parts of a given continuous visible flaw into different planes, or, in short, to make these flaws wavy. But in fact I have found no such waviness.

Hence I find here no escape from the inference that the lack of connection or relation between these little relics of blowholes indicates that the greater part of each of the original blowholes whence they have sprung has been welded up, leaving fragments so far scattered that their relation cannot be recognized. If I may hazard a guess, it is that these little fragments represent spots where a minute gas-bubble has persisted unabsorbed till the temperature has fallen too low for ready welding, and that there-

after the remaining gas has been re-absorbed, permitting the sides of the cavity to fold down flat.

24. Further support of the theory that there has been extensive welding is at hand in the fact that the lengthwise sections I and III, instead of having more gas-bubbles than the transverse sections II and IV have, as the non-welding theory implies, actually have fewer, as Table IV shows. Thus slices I and III taken together have only one gas-bubble, whereas II and IV have five.

This excess of bubbles in the crosswise over those in the lengthwise sections certainly strongly suggests that the final shape of the blowholes is somewhat as I have sketched at *G'* in Fig. 12, i. e., that their length in the finished plate lies lengthwise of the plate, and hence, by the reasoning in §§ 13, 19, 20, and 21, tends to show that much welding has occurred.

I may add that when I made the observations recorded in Table IV, I did not at all see the bearing of this fact. It was long afterwards that, by the process of reasoning given above, I inferred that the non-welding theory implied an excess of gas bubbles in the lengthwise sections; and only after I had drawn this inference did I turn to Table IV to see what the facts were.

25. *The Antecedent Probability That the Faces of the Blowholes Should Weld Up* seems to me almost irresistible; so that the above evidence that welding actually occurs seems to me simply to agree with what was next to certain antecedently. Those who work at high temperatures with metals like platinum which do not oxidize, find to their regret the extreme readiness with which the metallic surfaces stick together on mere contact and without detectable pressure. The faces of our blowholes are free from oxide. In the first pass their white-hot, soft, sticky, metallic walls are pressed together under enormous pressure, in the forward end of any individual blowhole, somewhat as sketched in Fig. 11. Knowing how instantaneously, and in general perfectly, steel skelp is welded in its single pass through the tube mill, my natural inference is that those walls must necessarily weld together to a greater or less extent in the first pass, though of course one cannot form a very firm and definite opinion beforehand as to how great that extent should be. Knowing, as we do, that clean surfaces of iron can be welded at much lower temperatures; knowing the great mobility, indeed the rapidity of travel, of the ferrite which precipitates

within solid hypo-eutectoid steel at temperatures even below 800° C., and the ease with which it assembles in fairly large envelopes, I find no difficulty in understanding that like welding should continue in many succeeding passes.

Of course, in passing from position e' to position f' (Fig. 10) the forward pressure of the gas should tend to re-open the tail which has been welded but a fraction of a second before. But this re-opening should be very far from complete: first, because the stiffness of the enclosing metal should resist this re-opening, and second, because, fresh as this weld is, it should reinforce this resistance. How far the freshness of the weld should limit its resistance to re-opening cannot be foretold with complete confidence. Of course we are not to be misled by the slowness with which wounds in animal and vegetable organisms knit together and gain strength. Certainly there is no such slowness of increase of cohesion in the weld in steel. We need not go so far as to assert that the weld reaches its maximum strength at the instant of contact in a differential of time; but the fact already referred to, that the weld in a steel tube is almost as strong as the solid unwelded metal, though in its single pass through the tube mill it is under pressure but a small fraction of a second, and though it cools thence very rapidly in the air, certainly goes to show that the weld between the walls of a blowhole should reach a very high degree of strength in passing say from position c to position e of Figs. 9 and 10, brief though the interval is.

Taking these considerations as a whole, they lead us to expect that, though the tail-welding need not always be complete and instantaneous, yet it should not fall far short of completeness in the early passes when the metal is at its stickiest.

26. *The Antecedent Probability of Gas Re-absorption* is strengthened by our present evidence tending to show that welding occurs. For in that this welding restricts the re-expansion of the gas which tends to occur in any given blowhole after passing the axial plane of the rolls, it of course restricts the fall of pressure which such re-expansion would have caused, and by thus lessening this fall of pressure favors re-absorption, which presumably must increase with the existing pressure. It is to be remembered that the re-absorption would naturally continue throughout the interval between passes.

27. *The Probable Course of Events* seems to me to be that the first pass welds up one end of the blowhole, and compresses the gas within it very greatly; that under this great pressure much of the gas re-dissolves in the surrounding incandescent metal, thus relieving the pressure; that the next pass further compresses the remaining gas, and that this second increase of pressure again accelerates the absorption of the gas by the metal; and so on. Each pass actually lessens the volume of the blowhole and the area of its still unwelded walls, and puts the gas under enormous pressure; in the very considerable interval between passes this pressure is relieved by the re-absorption of part of the gas, which is probably aided by the increasing solubility of the gas with the continuous fall of temperature. In the early passes when the metal is very sticky, tail-welding should go on rapidly. Thus it is a race between the welding up of the cavity and the re-absorption of the gas on one hand, and the cooling off of the metal on the other hand. In the present case the cooling seems to have outstripped the welding and absorption, so that some unwelded contacts and a very little unabsorbed gas remain.

Thus our present evidence seems to show that the gas is qualitatively absorbable, and the blowhole walls qualitatively weldable, just as I for one should certainly have assumed them to be, had not this been denied by implication by a metallurgist of distinction. If I am right in this, then I for one infer that the completion of the re-absorption of the gas and of the welding of the blowholes should be simply a question of mechanical engineering, of supplying the needed pressure for the needed time at the needed temperature; and that it is a question of dollars and cents whether, in making steel for any given purpose, it is profitable to supply these needed conditions so as to carry this effacement of blowholes to absolute completion, rather than to arrest it for instance at the stage found in these specimens.

And of course what I have said applies primarily to low-carbon steel like that experimented on. The higher the carbon the less confidently can welding be expected, and it may well be that even in rail steel the closing of blowholes may be prohibitorily difficult.

But the question is at best a rather difficult one. I have given my own interpretation of the evidence. If I am wrong I should be grateful to any friend who would set me right.

Looking back, while the experimental evidence which I have offered seems competent to answer the questions to which this paper is primarily addressed, touching the qualitative weldableness of the bubbles and expellableness of the gas, I have availed myself of the opportunity to go farther and speculate not a little about what occurs in rolling. Such speculation cannot be accepted as true unless verified by actual observations, on the principle which called for the direct observation of the planet which Leverrier's speculations had foretold, and the direct verification of Columbus's inference as to a short cut to the Indies. But it is not necessary, nor perhaps always best, that the speculation and the verification should be done by the same person. Nature prompts and fits some to speculate and others to verify; and here, as in so many cases, we may yield to Nature's rein. To-day, in the early dawn of science which accompanies our present crude civilization, the gain to the community which this subdivision of scientific labor may afford is little recognized.

28. *An Inference from the Foregoing Considerations.*—A variety of evidence, some of which was indicated in the previous paper,* tends to show that gases like those of the blowholes pass readily into and out of iron. The complete welding up of the blowholes seems to call for complete re-absorption of the gas which formed them. This re-absorption may well take some considerable time. A high temperature should favor it in two respects, (1) by increasing the pressure of the gas within the blowholes, and (2) by hastening the diffusion of the absorbed gas outwards from the immediate walls of the blowholes into the more remote metal, and so enabling those walls to absorb fresh lots of gas from the blowhole. It would seem probable that these influences of a high temperature, taken jointly, should outweigh its probable lowering of the solubility of the gas in the metal.

If this is true, then the "direct rolling" of rails and other objects (i. e., rolling direct from ingot to rail at a single heat) should be less favorable to the complete closing of blowholes than the "reheating" practice, in which the bloom into which the ingot is rolled is held in a special bloom-heating furnace before rolling into a rail. This sojourn of the bloom in the heating furnace would seem to favor the re-absorption of the gas. In rolling from

Proceedings, 1909. Vol. IX, p. 339.

ingot to bloom the blowholes should be much compressed, their gas left under great pressure, and the surrounding metal heavily charged with gas. During the sojourn in the bloom-heating furnace the gas in this surrounding metal has an opportunity to diffuse outwards into the metal more remote from the blowhole, and the gas still remaining in the blowholes has an opportunity to be re-absorbed by that metal. The very high temperature of this reheating should make these opportunities all the more effective.

Thus, because of this sojourn, when the reheated bloom enters the rail train its blowholes should contain less gas, and the metal surrounding those blowholes should be less charged with gas, and hence should absorb gas from those blowholes more greedily under the pressure in the rail train, than in direct rolling.

Again, the high temperature of the early passes after the reheating should favor the welding of the tails.

Hence, in fine, both the closing of the gas-bubbles proper and the welding of their traces should be more complete in "reheating" than in "direct rolling" practice. Direct experiment alone can decide whether these speculations are right, though the familiar fact that the proportion of second quality rails, i. e., defective rails, made is much greater in direct rolling than in reheating practice, is in general agreement with them.

FURTHER NOTES ON THE ANNEALING OF STEEL.

By William Campbell.

The following experiments are a continuation of some work on annealing, presented to the Society last year,* dealing with the treatment of cast material. The conclusions reached were that the metal was completely refined as regards grain size by heating to temperatures a little above Ac_{2-3}, except where there is a network of manganese sulphide or slag globules present, which prevents complete refining. A 0.35-per cent. carbon steel was refined by annealing it for one hour at 830° C.

In the discussion of the Report of Committee F, on the Heat Treatment of Steel,† Mr. J. M. Darke gave some interesting results on the annealing of cast open-hearth steel of 0.24 per cent. carbon, and showed that the best physical properties were obtained by annealing at 850° C. for six hours, although heating to 1000° C. for twelve hours did not cause overheating. The following figures taken from Mr. Darke's discussion show this:

Analysis of Steel.

Carbon	0.24	per cent.
Manganese	0.612	" "
Silicon	0.223	" "
Phosphorus	0.057	" "
Sulphur	0.037	" "

Test Results.

Treatment.	Yield Point, lbs. per sq. in.	Tensile Strength, lbs. per sq. in.	Elongation, per cent. in 2 ins.	Reduction of Area, per cent.
As Cast	30,755	66,010	16.9	19.45
850° C. for 6 hrs.	41,560	71,600	28.4	47.46
1000° C. for 12 hrs.	36,687	71,800	26.9	32.24

The material for the present work was open-hearth eye-bar steel, which failed to anneal properly at the works. It was received

* "Notes on the Annealing of Medium Carbon Steel:" William Campbell. *Proceedings*, 1909, Vol. IX, pp. 374 ff.

† *Ibid*, p. 217.

together with a piece of properly annealed steel for comparison. Table I gives the physical properties of the two sections after annealing, together with the analyses and the properties of the test specimens from the mill.

TABLE I.

	Steel 1. Annealing Poor.	Steel 2. Annealing Good.
EYE-BAR TESTS		
Section, ins.	7 by $2\frac{1}{4}$	8 by $1\frac{5}{8}$
Elastic Limit, lbs. per sq. in.	29,100	36,320
Ultimate Strength, lbs. per sq. in.	61,390	66,400
Elongation in 12 ins., per cent.	9.5	36.3
" " 29 ft., " "	...	10.7
" " 39 ft., " "	8.9	....
Reduction of Area, per cent.	9.0	40.0
Fracture	100% crystalline, square.	100% silky, half-cup.
SPECIMEN TESTS		
Elastic Limit, lbs. per sq. in.	43,490	42,120
Ultimate Strength, lbs. per sq. in.	69,250	69,590
Elongation in 8 ins., per cent.	27.5	28.1
Reduction of Area, per cent.	43.3	41.9
ANALYSIS		
Carbon, per cent.	0.28	0.30
Sulphur, per cent.	0.03	0.025
Phosphorus, per cent.	0.015	0.018
Manganese, per cent.	0.52	0.53
ANNEALING		
Temperature, deg. Cent.	3 times between 840° and 855°	790°

In the case of Steel 2 the desired results were obtained, but the ductility of Steel 1 has fallen off so much that it was suggested that the temperature of annealing might possibly have been high enough to cause overheating. Longitudinal sections were therefore cut from each, near the fracture, to see if the microstructure showed such overheating.

Fig. 1 shows the coarsest structure of Steel 1. This view was taken from near the outside of a section cut perpendicular to the width of the bar. Fig. 2, from near the center of the same

FIG. 1.—Steel 1. Coarsest Structure.

FIG. 2.—Steel 1. Finest Structure.

FIG. 3.—Steel 2. Finest Structure.

FIG. 4.—Steel 2. Coarsest Structure.

Steel 1: Carbon = 0.28 per cent. Steel 2: Carbon = 0.30 per cent.
Material as received. Magnification = 39 diameters.

section, shows the finest structure met with. The average size of grain is seen at the top and bottom of Fig. 1. The marked lamination of the white ferrite and dark-etching pearlite is to be noticed. Now contrast the grain size with that of Figs. 3 and 4, which show the normal and the coarsest structure seen in Steel 2. Of course, as the sections were taken near the fractures, allowance must be made for the reduction of area in each case; but allowing for this in Specimen 2 (in this case the thickness at the point photographed had been reduced from $1\frac{5}{8}$ ins. to $1\frac{1}{4}$ ins.), it is evident that the structure of Specimen 2 is much finer than that of Specimen 1, while both remain laminated, as in the case of material as rolled, without any annealing.

Longitudinal sections were cut parallel to the width of the bar, but the lamination was much less distinct, as is to be expected. The bands of ferrite had changed in section from thin to thick, just as the slag in one section of puddled-iron plate looks like a thread while in another it is plate-like. A mica-schist illustrates this idea. The structure of Steel 1, cut parallel to the width of the bar, is very similar to that shown in Fig. 5.

Now the question to decide was whether this coarse structure in Steel 1 was due to heating to 850° C., or whether it was that present originally in the steel. If the latter, then why should such strong lamination persist after heating above the *upper* critical points? At first sight it seemed that the steel could not possibly have been heated to the temperature given.

To throw some light on this point, a number of small pieces of this steel were heated to various temperatures below and above the critical points in a gas muffle and cooled in the air. The specimens were placed in the muffle next to a thermo-couple and slowly heated. When the temperature reached a desired point, it was held there for five minutes; then one piece was withdrawn and the heating continued for the remaining specimens. The critical points as determined by a Roberts-Austen photographic recorder were:

Ar_{3-2}	begins	740° to 745° C.	}	65° C.
Ar_1	at	675° " 680° C.	}	
Ac_1	at	750° " 755° C.		

The upper point on heating, Ac_{2-3}, was not shown on the curve, but it is approximately: $Ac_1 + 65°$ C. = 815° to 820° C.

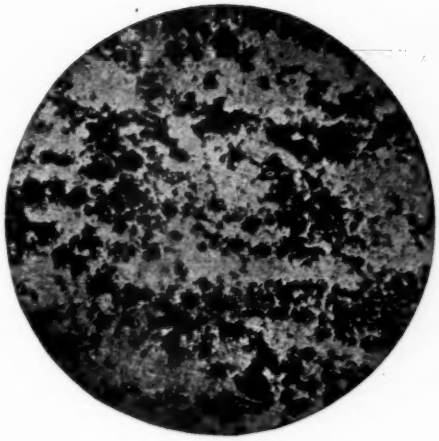

FIG. 5.—Heated to 715° C.

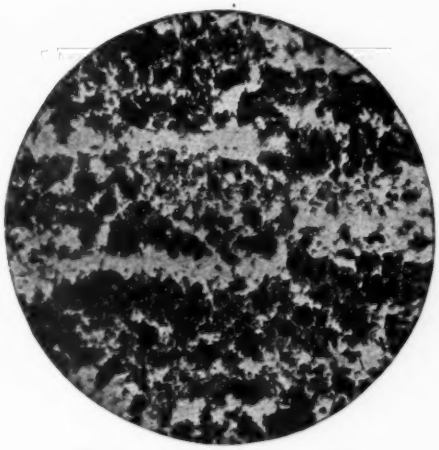

FIG. 6.—Heated to 750° C.

FIG. 7.—Heated to 775° C.

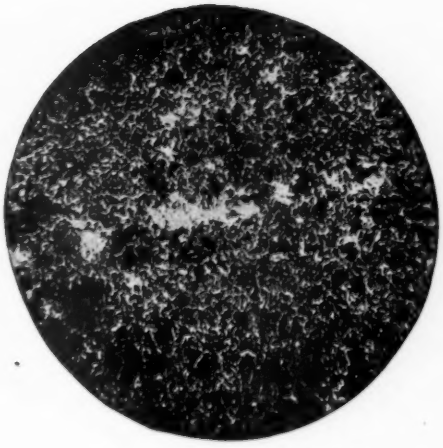

FIG. 8.—Heated to 800° C.

Steel 1: Carbon = 0.28 per cent.; Manganese = 0.52 per cent.
Magnification = 39 diameters.

Table II shows the temperatures of heating and the structures found in longitudinal sections cut parallel to the width of the bar.

TABLE II.

Steel No. 1. C. = 0.28, Mn. = 0.52.

Temperature.	Structure.	Fig. No.
715° C.....	Very coarse ferrite, similar to original bar.....	5.
750° "	Laminæ of ferrite strong, ground mass is refined	6.
775° "	About 25 per cent. of ferrite laminæ left	7.
800° "	Trace of coarse ferrite unabsorbed	8.
825° "	Complete refining. No coarse ferrite	9.
850° "	Structure similar.....	..
900° "	Refined but grain size coarsening.....	10.

Comparing Figs. 5 to 10, we see that the higher the temperature from 750° C. (Ac_1) on, the more of the coarse ferrite is absorbed, till at 825° C. refining has been completed and heating to higher temperatures tends to coarsen the grain. Also, in the refined specimens all trace of lamination has disappeared.

It is to be noted that in Figs. 9 and 10 the relative amount of ferrite envelopes to pearlite grains is much less than the ratio of the ferrite to the pearlite in Figs. 1 to 5. The same applies to a less extent to Figs. 6, 7, and 8. This is due, as has been pointed out before, to the fact that in cooling small pieces of steel in the air, the fall in temperature is very rapid and the normal amount of ferrite does not separate out. Had the specimens been slowly cooled, the ratio of ferrite to pearlite would have been greater. To show this, a section was cut from the sample used for the determination of the critical points, heated to 1045° C. in the electric furnace, and cooled slowly. The results of this treatment are shown in Figs. 11 and 12, and since the section was taken perpendicular to the width of the bar, these figures are directly comparable with Figs. 1 and 2. The grain is coarser than that of Fig. 10, but apparently finer than that of the original steel (Figs. 1 and 2), while the amount of ferrite is far in excess of that in Figs. 9 and 10. Lamination has entirely disappeared, except in one or two places where lines of manganese sulphide and slag are seen, as illustrated in Fig. 12. This specimen shows that overheating as indicated by the coarsening of the grain and the angular arrange-

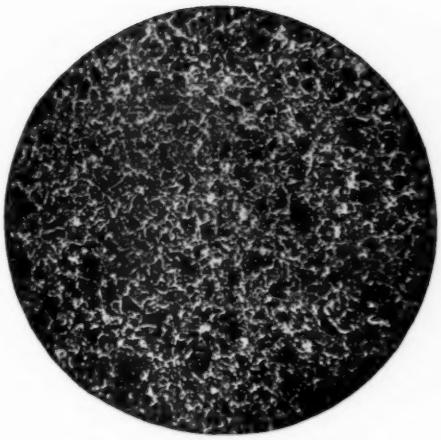

FIG. 9.—Heated to 825° C.

FIG. 10.—Heated to 900° C.

FIG. 11.—Heated to 1045° C.

FIG. 12.—Heated to 1045° C.
"Slag line."

Steel 1: Carbon = 0.28 per cent.; Manganese = 0.52 per cent.
Magnification = 39 diameters.

ment of the ferrite (as in Wiedmanstatten figures or in cast material) has begun.

From the above it may be inferred that, as in the case of cast material of medium or low carbon, so here with rolled steel: heating to just above Ac_1 refines the pearlite ground-mass only, while complete refining as shown by the disappearance of the last of the coarse laminæ of ferrite takes place only on the completion of the Ac_{2-3} change; for this particular steel at about 825° C. With such refining, all lamination of ferrite disappears except that caused by re-precipitation on lines of slag or manganese sulphide. In addition, the illustrations serve to emphasize again the difference in structure between furnace and air-cooled specimens as regards relative amounts of ferrite and pearlite, and hence as regards physical properties.

In regard to the original specimen, Steel 1, these results would tend to show that although the pyrometer may have indicated 850° C. as the temperature of the annealing furnace, the steel itself never reached a temperature of much over 750° C.

THE INFLUENCE OF TITANIUM ON SEGREGATION IN BESSEMER-RAIL STEEL.

By G. B. Waterhouse.

Segregation is one of the important questions before the steel-maker. It is therefore natural that for many years it should have engaged the attention of iron and steel metallurgists in different countries, and have given rise to an important literature. The author greatly regrets that owing to lack of time, he is unable to review this literature and bring together the more important findings.

In the following pages are presented the results recently obtained by the author on segregation in acid Bessemer-rail steel. They point in the same direction as those published in 1905 by Talbot, which showed the important influence of aluminum in greatly retarding segregation in certain cases.

In the present instance titanium, when rightly applied in the proper amount, is also found to retard segregation of sulphur, phosphorus, and carbon, in what is normally quiet, quick-setting steel. In all commercial steels the bulk of the ingot must be used, and it is believed that the results given below are of importance, showing as they do one way in which segregation may be considerably controlled.

Results with Ingots.

The ingots used were from an ordinary rail-steel heat, and from a heat to which had been added 64 lbs. of ferro-titanium, which amounted to only 0.25 per cent. of the weight of the heat. The ordinary steel was made in the usual way. After the heat was turned down, the proper amount of molten spiegel was poured into the vessel. The heat was held there a short time, poured into the ladle, and then through a $1\frac{1}{2}$-in. nozzle into the ingot molds.

There were six molds. After three ingots had been poured, a ladle test was taken. The third ingot of the six was allowed to

cool while still standing on its stool, and was then cut through longitudinally.

The heat in which ferro-titanium was used was made in exactly

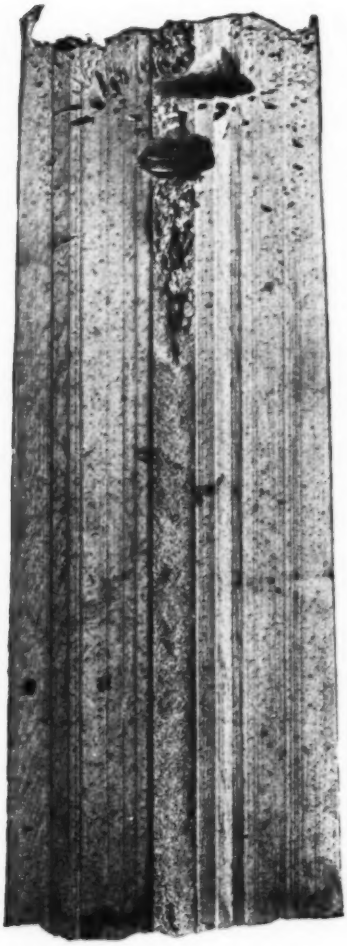

FIG. 1.—Ordinary Steel Ingot.

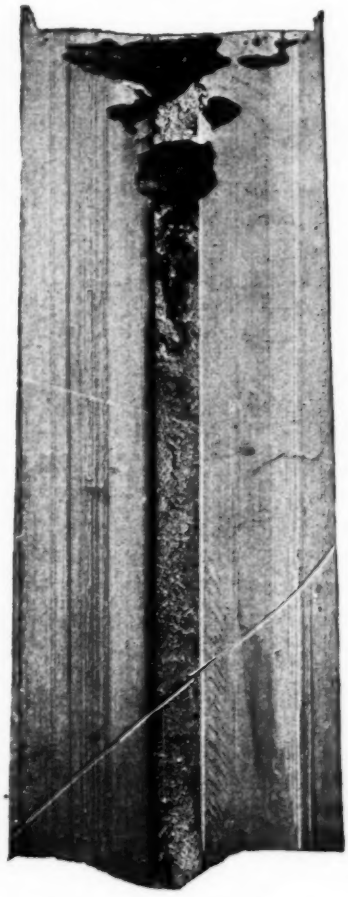

FIG. 2.—Titanium Steel Ingot.

the same way. As the steel was poured into the ladle, the alloy was shovelled in; the heat was then held in the ladle for three minutes before pouring the ingots. In this case also, the third ingot of

the heat was cooled in an upright position and cut through longitudinally. An analysis of the ferro-titanium gave:

Carbon	10.50 per cent.
Titanium	11.60 "
Iron	74.12 "
Silicon	1.60 "
Manganese	0.30 "
Calcium	trace

Photographs of the ordinary and titanium ingots are shown in Figs. 1 and 2. The two large cracks running across the latter are due to cracks in the negative. The noticeable feature is the increased soundness of the titanium steel, due to the concentration of the blowholes in the pipe cavity.

The analyses of the ladle tests from the two heats were as follows:

	Carbon, per cent.	Sulphur, per cent.	Phosphorus, per cent.	Silicon, per cent.	Manganese, per cent.
Ordinary steel	0.44	0.098	0.088	0.117	0.91
Titanium steel	0.47	0.068	0.093	0.118	0.95

No trace of titanium could be found in the latter steel, so that it is not, strictly speaking, a titanium steel, but will be called so for the purpose of distinction.

In the accompanying diagrams, Figs. 3 to 8 inclusive, are shown the results obtained from determinations for sulphur, phosphorus, and carbon. A $\frac{13}{16}$-in. drill was used, and drillings were taken to a depth of $\frac{5}{8}$ in. The diagrams are drawn to scale, so that the location of the drillings can be readily seen. The methods used were the same for all the samples and all the determinations were made by one man. The results are briefly considered in order.

Sulphur.—This element segregates the most. In the ordinary steel it has risen from 0.098 per cent. in the ladle test to a maximum of 0.223, and there is a considerable area with more than 0.147, which is 50 per cent. more than the ladle test. In the case of the titanium ingot, the contrast is very remarkable. The greatest result is 0.101, which is not quite 50 per cent. more than the ladle test, 0.068, and the segregated area is very much smaller than in the case of the ordinary ingot. It is true that there are two factors which may partly account for this difference in results; the titanium ingot is somewhat smaller, and there is less sulphur in

the steel as a whole. The fact remains, however, that there is much less segregation of sulphur in the titanium than in the ordinary steel.

Phosphorus.—In the ordinary steel the phosphorus has risen

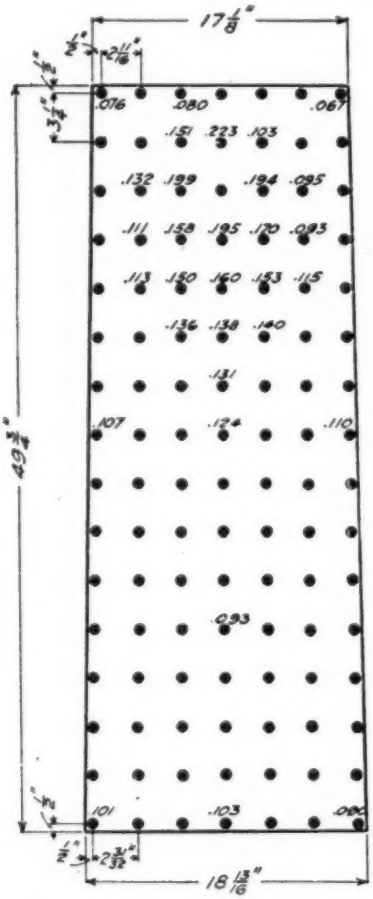

FIG. 3.—Normal Ingot, half section. Sulphur in ordinary steel.

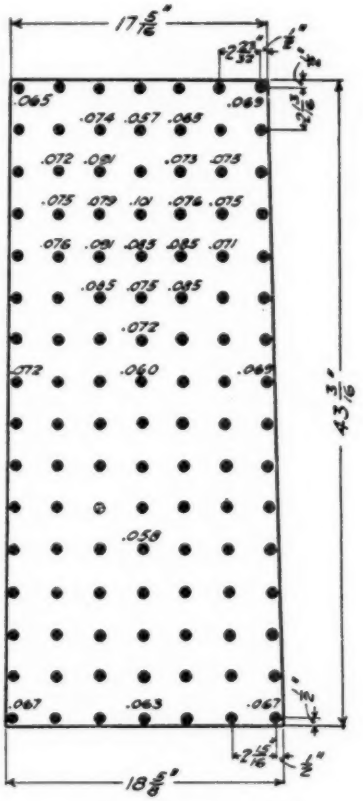

FIG. 4.—Titanium Ingot, half section. Sulphur in titanium steel.

from 0.088 per cent. in the ladle test to a maximum of 0.167, and here also the segregated area is seen to be considerable. In the titanium steel the maximum is 0.124, starting with a ladle test of 0.093, and the segregated area is more restricted than in the case

of the ordinary steel. The ordinary steel is in a better condition to start with than the titanium steel, as it has slightly less in amount (0.088 as compared with 0.093), so that the behavior of the phosphorus is a good test of the preventive power of the

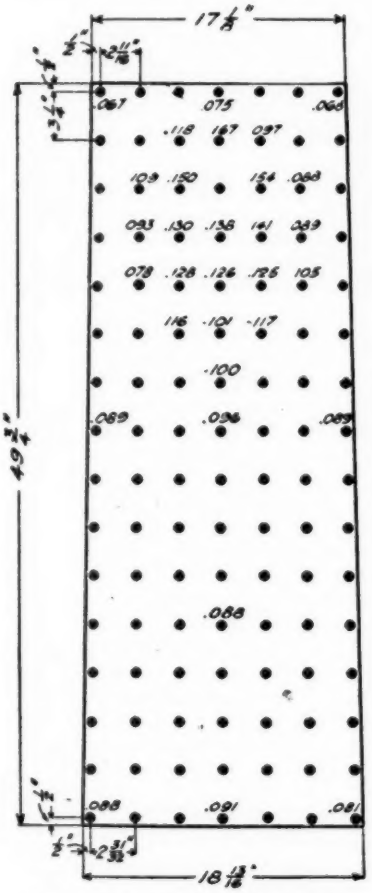

FIG. 5.—Normal Ingot, half section. Phosphorus in ordinary steel.

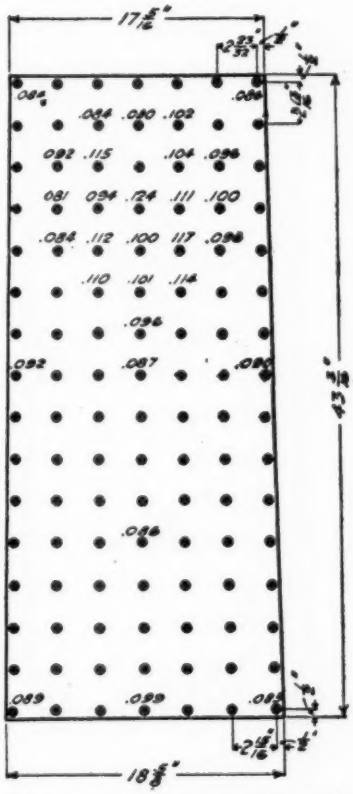

FIG. 6.—Titanium Ingot, half section. Phosphorus in titanium steel.

titanium. The results given in the diagrams (Figs. 5 and 6) show it to have been effective.

Carbon.—Here again the titanium steel shows less segregation than the ordinary steel, and it must be remembered that it starts

with 0.47 as compared with 0.44 per cent. The highest results found are 0.67 in the one case and 0.69 in the other, and the diagrams show that the ordinary steel again has the larger segregated area.

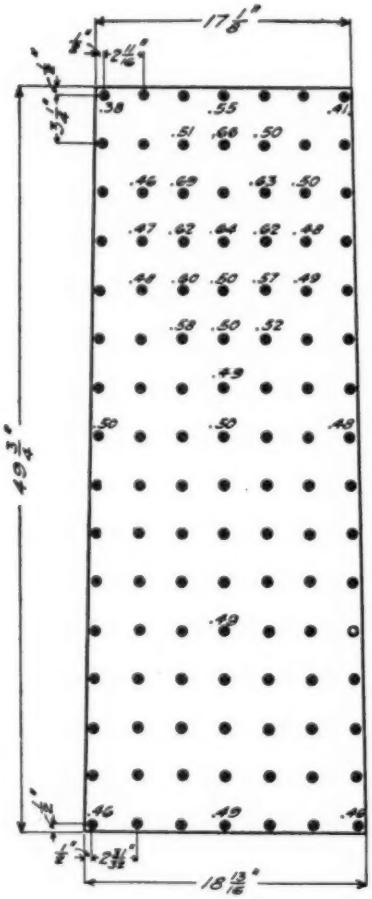

FIG. 7.—Normal Ingot, half section. Carbon in ordinary steel.

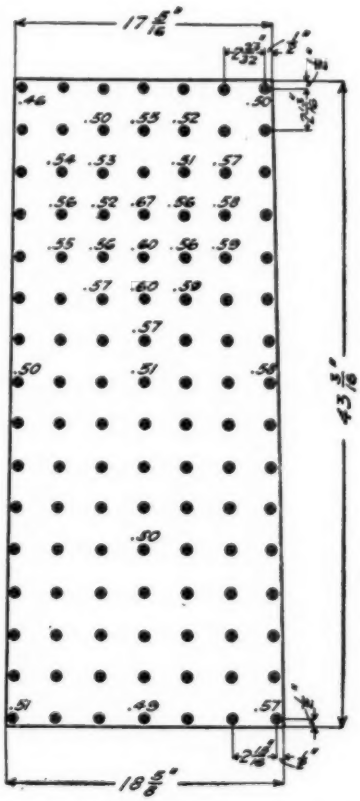

FIG. 8.—Titanium Ingot, half section. Carbon in titanium steel.

The results of the silicon and manganese determinations are not given; they are somewhat erratic in each case, but do not exhibit segregation.

RESULTS WITH RAILS.

It was felt desirable to make careful experiments with the entire length of rails from two ingots, one of ordinary steel and one of titanium steel. Among other reasons, the results given above

TABLE I.—ANALYSES OF "A" RAILS.

Distance from Top of "A" Rail.	Carbon, per cent.		Sulphur, per cent.		Phosphorus, per cent.		Silicon, per cent.		Manganese, per cent.	
	Titanium.	Ordinary.	Titanium.	Ordinary.	Titanium.	Ordinary.	Titanium.	Ordinary.	Titanium.	Ordinary.
0′2″	0.52	0.49	0.042	0.041	0.094	0.090	0.154	0.158	0.91	0.93
1′2″	53	47	042	038	092	091				
2′2″	53	49	042	039	093	093				
3′2″	53	49	044	041	092	092				
4′2″	52	49	044	039	094	089				
5′2″	53	48	044	041	094	091				
6′2″	53	47	042	040	096	093				
7′2″	54	47	043	042	096	092				
8′2″	54	48	042	041	099	095				
9′2″	54	48	042	041	095	091				
10′2″	54	50	043	050	099	088	161	177	93	97
11′2″	55	52	043	048	100	088				
12′2″	54	51	045	046	101	094				
13′2″	54	50	045	054	102	104				
14′2″	54	50	044	051	100	094				
15′2″	54	51	043	054	102	102				
16′2″	54	47	045	051	100	114				
17′2″	54	48	045	053	103	106				
18′2″	55	49	044	046	096	114				
19′2″	55	47	043	048	093	104				
20′2″	55	46	044	046	101	101	160	167	95	99
21′2″	54	47	043	048	095	107				
22′2″	54	46	043	049	098	105				
23′2″	54	54	044	054	101	108				
24′2″	54	55	044	050	100	098				
25′2″	54	54	044	051	102	097				
26′2″	54	56	045	051	100	100				
27′2″	54	53	043	051	101	102				
28′2″	56	52	045	050	104	107				
29′2″	54	52	045	051	100	100				
30′2″	54	53	046	051	098	104	160	172	95	97
31′2″	55	52	046	048	103	102				
32′2″	56	52	049	051	101	104				

do not represent those of regular practice, in which the ingots are placed in the soaking pits while the interior is still molten, and are rolled when solid throughout. It was thought that in the latter case, where the same opportunity was not given, there would not be found the same amount of segregation. Accordingly, two heats

of steel were made as nearly as possible under the same conditions, except that in one case 75 lbs. (0.3 per cent.) of ferro-titanium was used and the steel held for three minutes in the ladle before pouring. In each case the third ingot of the heat was taken. The ingots were three-rail length, and the section rolled was the Dudley 100-lb. rail. The rails were marked A, B, and C, being respectively the top, middle, and bottom rails from the ingots.

TABLE II.—ANALYSES OF "B" RAILS.

Distance from Top of "A" Rail.	Carbon, per cent.		Sulphur, per cent.		Phosphorus, per cent.		Silicon, per cent.		Manganese, per cent.	
	Titanium.	Ordinary.	Titanium.	Ordinary.	Titanium.	Ordinary.	Titanium.	Ordinary.	Titanium.	Ordinary.
33′8″	0.54	0.52	0.047	0.050	0.098	0.098				
35′2″	56	51	046	049	096	112				
36′8″	55	52	045	050	096	110				
38′2″	55	51	045	043	101	096				
39′8″	54	52	046	050	100	102				
41′2″	54	51	045	051	099	106				
42′8″	54	52	045	046	103	110				
44′2″	55	52	045	051	106	104	0.170	0.158	0.96	0.95
45′8″	56	53	045	048	105	100				
47′2″	54	53	043	048	103	105				
48′8″	55	....	045	....	098	....				
50′2″	55	53	045	048	103	100				
51′8″	54	53	043	048	095	101				
53′2″	55	53	042	047	106	102				
54′8″	54	52	041	047	094	096				
56′2″	54	53	044	047	100	100				
57′8″	52	53	044	047	098	101				
59′2″	50	53	040	047	098	101	157	166	97	94
60′8″	52	52	041	047	098	106				
62′2″	50	51	041	047	096	102				
63′8″	52	52	042	040	096	100				
65′2″	53	53	043	052	097	099				

The drillings for analysis were obtained in the side of the head with a $\frac{13}{16}$-in. drill, going well past the center in each case, and to a uniform depth each time. Beginning 2 ins. from the top of the "A" rails, drillings were taken every 12 ins., and in the "B" and "C" rails, every 18 ins.

The analyses of the ladle tests of these two heats were as follows:

	Carbon, per cent.	Sulphur, per cent.	Phosphorus, per cent.	Silicon, per cent.	Manganese, per cent.
Ordinary steel	0.49	0.044	0.102	0.162	0.92
Titanium steel	0.51	0.041	0.102	0.172	0.92

The results obtained on the drillings are given in Tables I, II, and III. In the case of each rail, the distance given is from the top of the "A" rail.

In this case also it is seen that the use of ferro-titanium has lessened the segregation. The sulphur in the ordinary steel varies from 0.038 to 0.054 per cent., and in the titanium steel from 0.039

TABLE III.—ANALYSES OF "C" RAILS.

Distance from Top of "A" Rail.	Carbon, per cent.		Sulphur, per cent.		Phosphorus, per cent.		Silicon, per cent.		Manganese, per cent.	
	Titanium.	Ordinary.	Titanium.	Ordinary.	Titanium.	Ordinary.	Titanium.	Ordinary.	Titanium.	Ordinary.
66′8″	0.51	0.53	0.041	0.050	0.097	0.100				
68′2″	54	53	042	051	099	098				
69′8″	51	52	042	049	099	099				
71′2″	52	52	041	052	092	092				
72′8″	50	52	042	057	092	096				
74′2″	50	52	041	053	093	098	0.172	0.172	0.92	0.93
75′8″	51	52	041	053	093	090				
77′2″	51	52	040	050	095	088				
78′8″	53	51	041	049	101	086				
80′2″	52	52	041	047	100	084				
81′8″	52	53	040	046	098	092				
83′2″	52	53	040	048	104	087				
84′8″	52	53	041	050	098	098				
86′2″	53	53	040	053	090	093				
87′8″	53	54	040	052	102	095				
89′2″	53	53	039	048	104	096	147	141	90	99
90′8″	51	53	039	052	092	098				
92′2″	51	53	040	052	095	094				
93′8″	51	52	040	050	099	095				
95′2″	50	53	040	053	102	090				
96′8″	51	51	039	042	092	084				
98′2″	51	52	040	044	091	086				

to 0.049 per cent. The phosphorus in the ordinary steel varies from 0.084 to 0.114 per cent., and in the titanium steel from 0.090 to 0.105 per cent. Lastly, the carbon in the ordinary steel varies from 0.46 to 0.56 per cent., but in the titanium steel only from 0.50 to 0.56 per cent.

The use of the alloy, therefore, has brought about much more uniformity in the steel, and, as remarked before, has lessened the segregation.

DISCUSSION.

The President. THE PRESIDENT.—This is a valuable contribution to our knowledge on this subject. I think it may be said that quiescence is one of the things which most strongly opposes segregation. We can readily understand that the quiet steel shows a great deal of growing out of pine-tree crystals from the side and a land-locking of the molten metal, so that segregation is interfered with by this rapid growth, this out-shooting of the crystals into the molten interior, so that much of the still molten metal is land-locked, and the segregation is prevented from taking place. That is to say, the centerward travel of the molten part of the steel is impeded by this growth. It seems that anything tending to cause quiet ought to lessen segregation, and anything that tends to cause activity or wildness ought to lead to segregation. Now the action of titanium is strongly analogous to that of aluminum. Both act by deoxidizing the steel and quieting it. It is most interesting, I think, to have that confirmed from another point of view by Mr. Waterhouse, who now shows that another quieting element, titanium, also lessens segregation.

Mr. Stevenson. MR. A. A. STEVENSON.—I do not see why aluminum, or a little more silicon, would not have about the same effect.

Mr. Souther. MR. HENRY SOUTHER.—It seems to me that one element has not been brought out by Mr. Waterhouse as clearly as it ought to be. The statement is made that the heat was held three minutes in the ladle. Now three minutes on a cold heat is a serious matter. It means that the ingot is going to chill very quickly. Segregation cannot take place anyway. I realize perfectly that it is very hard to hold all conditions the same, whether during the addition of titanium, vanadium, aluminum, or anything else. It appears to me that the effect of temperature is quite as important as that of the titanium itself. I should like to ask Mr. Waterhouse whether he knows of a possible theory tending to explain why titanium should behave differently from the ordinary quieting or deoxidizing elements.

Mr. Waterhouse. MR. G. B. WATERHOUSE.—Mr. Souther's remarks are perfectly correct, but it is impossible to pour a heat through a 1½-in. nozzle and have much less temperature in such steel than in

ordinary steel. It is the practice in the mill to pour a heat at the lowest possible temperature, and the practice when holding in the ladle is not very different from what it is in the ordinary steel. At the same time, of course, some of the results on segregation may come from pouring a little colder. I thought it best to give actual results, and to leave the theorizing to others who have perhaps more time. I am not attempting to give an inference as to what may happen. Of course the titanium may quiet the steel, and there is no question but that aluminum works the same way. The steel I have reference to is a normally quiet quick-setting steel; the open-hearth fairly low carbon steels that Mr. Talbot worked with were presumably not as quiet and quick-setting as the steel mentioned here. **Mr. Waterhouse.**

THE PRESIDENT.—Are we to understand, Mr. Waterhouse, that the conditions in pouring these bars were not strictly identical, and that the steel containing titanium was held a little longer than the other? **The President.**

MR. WATERHOUSE.—Yes, sir; but my recollection is that the temperatures were almost identical. **Mr. Waterhouse.**

MR. JAMES A. AUPPERLE.—I should like to ask whether Mr. Waterhouse has found the effect of titanium upon the nitrogen and oxygen contents of the open-hearth steel. **Mr. Aupperle.**

MR. WATERHOUSE.—Those ingots which were worked upon were not of open-hearth steel. We have used titanium only in a very few cases with open-hearth steel, and I have no results to give on that. Again, on the Bessemer steel I have made so few determinations that there is nothing I should care to announce at this time. **Mr. Waterhouse.**

THE PRESIDENT.—The question which Mr. Souther raises is as to the danger of chilling by holding the steel in the ladle. It would seem, however, that there is also much to be gained by holding the metal in the ladle for a reasonable interval. The question would seem to be, whether with the large charges of to-day any harm is done by pouring at such a temperature as would enable the steel to remain for two or three minutes, or even longer, in the ladle, without danger of becoming unduly cold. The feeling once was that it was necessarily very injurious to blow at a temperature high enough to permit a considerable period of rest in the ladle for the quieting to take place; but it would seem as if that was rather a mistake, and that it was altogether practicable to have the temperature of the blow high enough to permit this. **The President.**

LOW-CARBON STREAKS IN OPEN-HEARTH RAILS.

By M. H. Wickhorst.

During 1908 and 1909, the Chicago, Burlington and Quincy Railroad Company obtained some open-hearth rails which developed a peculiar kind of failure, the study of which proved very interesting. The nature of the failure caused considerable alarm at first, but the remedy was easily applied after the cause was determined. The failures consisted of the rails splitting through the head in various directions, through the web vertically or diagonally, vertically from the head to the base, and in other ways. As a part of the investigation, the rails were examined by cutting sections from the defective portions, polishing highly, and etching with picric acid solution in alcohol. The method of preparing, etching, and photographing the rail section was about as given in the following description of a method for etching rails.

Rail Etching.

Preparation of Section.—A slice of the rail $\frac{1}{4}$ in. or more in thickness is cut with a cold saw or circular cutter, care being taken

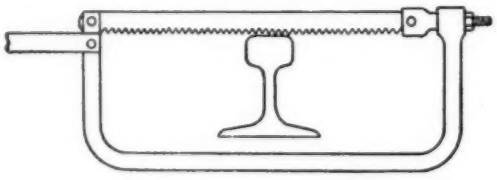

Fig. 1

to get the cut surfaces as even as possible. Where available, probably the quickest and most satisfactory method is to use a circular saw. In case a machine-driven hack saw is used, it is best to have the saw frame in an inverted position, with the frame surrounding the rail (see Fig. 1), so that the weight of the frame may hang below the cutting blade, as this position is more apt to give a straight cut.

After the slice is obtained, one of the cut surfaces is filed or planed to a plane surface. The rail slice is then secured in any hand clamps suitable for holding the section during the polishing operations. In polishing the rail sections, cast-iron discs at least 12 ins. in diameter are used, as shown in Fig. 2. Emery cloth is attached to the face of the disc, preferably by means of a fairly

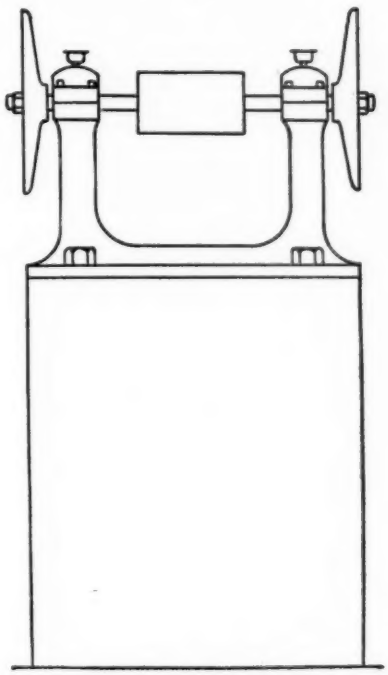

FIG. 2.

light coat of rather soft asphalt. The rail section should first be ground with No. 1 emery cloth and then with No. 00. The section is then polished with tripoli and finally with rouge. These polishing powders are applied in a moist condition to a canvas-covered disc. When the surface is intended for further examination with the microscope and microphotographing, a very high mirror polish is necessary and the surface must be free from even very minute scratches, such as show only under the microscope. When, however, it is intended only to examine for structural defects and streaks, so high a polish is not necessary.

Etching and Its Interpretation.—The rail section is etched by holding it in a tray of a five-per cent. solution of picric acid in alcohol. The etching generally requires from one to two minutes. When the rail section is taken from the acid, it is wiped with cotton saturated with alcohol. The picric acid does not color the ferrite or carbonless part of the steel structure; the carbon-bearing part, however, is colored somewhat in proportion to the content of carbon.

Photographing.—As the picric acid has no effect on the ferrite or carbon-free iron, streaks of low-carbon material are left with their full brightness, and in order to show these streaks properly,

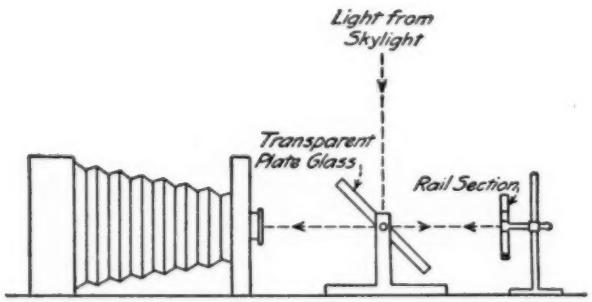

FIG. 3.

the light in photographing should be reflected perpendicularly from the specimen into the camera. A desirable arrangement is shown in Fig. 3, where daylight from a skylight is thrown on an oblique plate of glass, reflected onto the specimen, and then perpendicularly back through the glass into the camera. It is practically the same arrangement as the vertical illuminator used on a microscope.

SOME TYPICAL FAILURES.

When etched as above described, most of the split rails showed light streaks or patches, indicating treaks of metal low in carbon. Some typical etched sections of 90-lb. rails are shown in Figs. 4 to 9 inc usive, and it will be noticed that the failures occurred along the streaks. The rails shown in Figs. 8 and 9 had light

FIG. 4.

FIG. 5.

FIG. 6.

FIG. 7.

areas big enough to allow getting samples for analysis, and the results obtained are as follows:

		Rail in Fig. 8.		Rail in Fig. 9.	
		Normal.	White Band.	Normal.	White Streak.
Carbon,	per cent.	0.69	0.28	0.78	0.35
Phosphorus,	" "	0.037	0.091	0.036	0.073
Sulphur,	" "	0.034	0.048	0.030	....
Manganese,	" "	0.94	0.64	0.85	....
Silicon,	" "	0.15	0.09	....	0.15

FIG. 8.

FIG. 9.

Small white streaks examined under the microscope generally show a nucleus of slag, indicating that the slag in some way causes a reduction in the amount of carbon. The rail shown in Fig. 9 also contains a large mass of non-metallic material contiguous to the white band; so it was at first thought that slag in the metal caused the white streaks, possibly by oxidizing the carbon. This may perhaps be true of small streaks, but it was later learned that it was the practice at the mill that made these rails to put small soft Bessemer-steel plates on the stools of the molds to reduce the cut ing out of the stools by the hot metal. These plates, it seems, get churned up with the rest of the metal, and melt partly or

wholly; but before becoming thoroughly mixed with the main body of steel, the metal sets, leaving streaks as shown in the figures. It had been thought that the first metal poured would set and hold the plate at the bottom of the ingot, where it would be sheared off; but as soon as it appeared that the plates caused streaks as shown, the practice was promptly stopped. A few similar failures have been noted in rails from other mills, but whether due to a similar cause has not been determined.

DISCUSSION.

Mr. Hunt.

MR. ROBERT W. HUNT (*by letter*).—Mr. Wickhorst's paper on "Low-Carbon Streaks in Open-hearth Rails" is interesting and instructive as showing how that which to the most intelligent and progressive of practical men may seem safe practice, will produce decidedly undesirable results.

It is well known that one of the troublesome details in making the large ingots incident to taking care of the heavy heats from the modern open-hearth furnace, is the cutting of the cast-iron stools upon which the ingot molds set, which results not only in their rapid destruction, but also in their sticking, from partial welding, to the lower end of the ingots. Many plans to lessen, if not to entirely avoid this trouble, have been and are used by steel makers.

During the latter part of 1909, while making an examination of some basic open-hearth rails which had proved defective after a service of but a few months, the metallurgical department of my firm was surprised to find, on the etched section of the rails, distinct and well-formed figures indicating that something had been rolled into the rail entirely foreign to its normal composition and structure. Many solutions were suggested to us, among others that certain scrap additions to the open-hearth furnace had, by some unordinary action, passed entirely unassimilated to the ingot and thus, of course, to the rail. Consideration of such a possibility promptly checked further discussion in this direction, and a more simple physical explanation was looked for. As relating to some of the specimens, it was urged by a client that they gave evidence of the presence of sulphide of manganese or other slags. The shape of the figures, as they appeared in cross sections, and the chemical analyses, resembled so closely the section and composition of a familiar type of Bessemer-steel tie plate, that a review of the practice at the mill where the rails were produced gave a simple cause of the trouble.

The mill, casting a large ingot 20 by 24 ins. in section, about 72 ins. long, and weighing close to 4 tons, had the usual difficulty from cut stools and stickers. To overcome the trouble, tie-plate

scrap was thrown into the ingot molds before the casting of ingots began, with a view of forming a false bottom upon which the falling liquid steel would strike, thus preventing the cutting and sticking. Naturally, the tie plates would rest on the stools in an uneven manner, and thus be susceptible to the churning action of the falling Mr. Hunt.

FIG. 1.

stream of molten steel flowing from a 2-in. nozzle in the ladle under a tremendous static pressure. But it was expected that the high heat of the molten steel would either melt the cold scrap and thus assimilate it with the greater mass, or else the scrap would remain at the extreme bottom of the ingot and be eliminated by the sheared discard from the end of the bloom into which the ingot

FIG. 2.

would be rolled, and which represented its bottom or stool contact end.

That the actual results were far different was proven by our examinations, as we found evidences of the tie-plate scrap in various locations in the rails rolled from ingots which had been so cast; sometimes in the head, or the base, or the web, and

Mr. Hunt. occasionally so distorted and elongated as to occur in all three places. There had been no concealment of the casting practice, but it was confidently believed, as already stated, that the large discard from the bottom of the ingot would eliminate the possibility of the tie plates appearing in the rails. This view was particularly strengthened by the bottoms of ingots and blooms frequently carrying the scrap in plain view, and the crop shearing seemed to eliminate it.

Fig. 1 shows one of the examined rails containing four separate tie plates, and the actual section of the tie plate seen in the upper

FIG. 3.

left-hand corner of the head is shown in Fig. 2. Another typical case is shown in Fig. 3, where the breaking down of the rail after service of a few months is apparent. Various other effects in service have appeared. In many cases the steel of the head curled up like shavings of wood as the wear progressed downward toward the surface of the softer steel; in other cases the head was crushed or split; the results always indicating what other tests have demonstrated, namely, that there has been no actual welding between the steel of the rail and that of the impinged tie plate.

It must be remembered that tie-plate scrap of all shapes was used, sometimes the crop end of the stock, and sometimes mispunched or badly sheared plates, so that various effects and distorted figures could easily be produced in the rail section.

Sometimes also the temperature of the molten steel of the ingot was doubtless sufficient to partially dissolve small pieces of the scrap tie plate, and this effect has manifested itself as ferrite at various times. Fig. 4 is an illustration of such a case; the light-colored material, which the microscope discloses as the ferrite of a low-carbon steel, is clearly seen in the picture. A most pronounced example of this character is shown in Fig. 5, where a split extends through head, web and base, separating a short length of the rail in two nearly equal parts with practically no cohesion between them. In this instance, examination under the microscope showed **Mr. Hunt.**

FIG. 4.

FIG. 5.

positively the presence of intermittent streaks of ferrite along the line of fracture.

The effects produced by this practice have been found in rails from all locations in the ingot, and at least one case has been known where the "B" rail of a seven-rail ingot contained a clearly defined tie plate, plainly proving that the scrap had floated upward in the molten metal of the ingot a distance of over five feet.

The rail makers promptly stopped the disastrous practice when their attention was called to the solution of the rail failures, and thus at least one cause of defective rails has been removed.

MR. M. H. WICKHORST (*by letter*).—This matter of foreign material included in rails from the mill under discussion, engaged **Mr. Wickhorst.**

Mr. Wickhorst. the attention of a number of investigators, and probably the R. W. Hunt Company is to be given the major part of the cred for getting at the bottom of the cause of these failures. Mr. Hunt makes the statement that the effect produced by putting scrap on the stools shows itself in rails from all locations in the ingot, and this is confirmed by a tabulation I made of a certain lot of thirty-six rails that failed as described in my paper. The rails, by position in the ingot, may be classed as follows:

A, 3; B, 11; C, 6; D, 6; E, 1; F, 3; G, 6; total, 36.

ELONGATION AND DUCTILITY TESTS OF RAIL SECTIONS UNDER THE MANUFACTURERS' STANDARD DROP-TESTING MACHINE.

By P. H. Dudley.

In the recently adopted Manufacturers' standard drop-testing machine, the dies of the hammer and of the supports have each a radius of 5 ins. The supports are set 3 ft. apart upon a cast-iron block or anvil weighing 20,000 lbs., which is supported upon springs to insure that the energy of the blow will be expended principally in deflecting and producing a permanent set in the rail butt under test. In the older machines, the supports for the butt were arranged upon a small foundation, and the rebound of a 2,000-lb. hammer was as large as 12 to 14 ins., while in the present machine it is confined to 3 or 4 ins. The decided advantage of the newer method is that the energy can be concentrated upon the same portion of metal for more than one blow. Therefore, the elongation per inch for the second blow is but little less than that for the first, while in the older machines it was only about half as great.

Also, the ductility of the metal may be uniformly exhausted and determined by two, three or more blows. This is impossible with the older machines; the best which can be done is a single blow upon the side, which would show from 12 to 16 per cent. ductility for the maximum inch, though rarely breaking the section. This does not exhaust the ductility of the metal. Finally, the elongation in the base or head of the rail—depending upon which is down on the supports—due to the impact of the hammer of the present machine, is greater for a given height of drop than that obtained with the older machines having a larger radius of hammer, which distributed the effect of the blow over a longer portion of the rail.

The drop test upon rail sections as fabricated is intended to ascertain the toughness and ductility of the metal, and is required in all specifications for every heat, although the elongations are not generally measured. The metal of the rail section

has elastic and plastic properties; when the elastic limit is passed, the elongations are due to the plastic properties of the metal. Therefore, there is in addition to the permanent set of the butt an elastic "reaction" about one-third or one-half as great as the permanent set, which, however, does not affect the ductility.

The maximum elongation per inch can be obtained by stamping the base, head, or edge of the base of the butt, as the case may be, before testing with a spacing bar of six spaced inches, directly under the point of impact for either a single blow or for two or more required to exhaust the ductility of the metal. These six inches include about two-thirds of the metal affected by the impact. The elongation of each inch is measured by a flexible steel rule divided into hundredths of an inch; therefore, should the inch after test measure 1.05 ins., it would indicate 5 per cent. elongation for that inch, and by measuring each inch the total for the six inches would be obtained. Each inch, therefore, is re-measured after a blow and the measurement recorded as shown in Table I.

A single blow may or may not exhaust the ductility of the metal, but whether it has a greater range than 5 to 7 per cent. as shown by a single blow depends jointly upon the mechanical properties of the section and the physical properties of the metal, and unless the test butt is given more than one blow the range of ductility and its maximum value are not disclosed.

I have measured the elongation in the base of rails since 1891. The drop test was practically obsolete when I started to make the high-carbon and low-phosphorus rails in 1891, and it was necessary to reinstate it for testing them. I was at first obliged to use a freely falling weight of 2,000 lbs. with a drop of 20 ft. or more, the supports resting upon ingots imbedded in the earth.

The elongation in the base of a 6-in., 100-lb. rail, with a moment of inertia of 48.5 ins.,[4] under a single blow for an 18-ft. fall in the present drop-testing machine, will be from 6 to 7 per cent. for a steel of 0.50 carbon, 0.10 phosphorus, and 1.00 manganese. The elongation of the metal under the drop-testing machine compares favorably with that obtained by static loads in the tension-testing machine. The tendency is an increase of possibly one or more per cent., owing to the fact that the base of the rail in stretching does not neck as in the case of a tensile specimen. It is also probable that the energy converted into heat, which raises the

temperature of the butt under successive blows, slightly increases the ductility of the metal. The possibility of quickly determining the ductility of the metal in the section from hour to hour as rolled is one of great value, as conditions of manufacture can be followed as they occur.

A rolled section of pure iron would show a total elongation under the drop of 40 to 45 per cent. for two or three inches directly under the point of impact. By adding carbon to the iron, there is, as would be expected, a reduction in the elongation of the metal. When I introduced the high-carbon rails (carbon, 0.60; phosphorus, 0.06), I thought it possible to secure a range of ductility of 12 to 15 per cent. This was considered doubtful, but in actual practice it was obtained from a majority of the heats. The provision was made that 90 per cent. of the test butts from the 80-, 95-, and 100-lb. rails must not fail under a tup of 2,000 lbs. falling 20 ft., and that if a butt should break yet give 4 per cent. elongation, the heat represented by that butt would be accepted. The maximum elongation in the 100-lb. rails for one blow was 5 per cent. for two or three inches, while for the 80-lb. rails it was 6 per cent. These rails after twelve to eighteen years' service in the track have developed only a small percentage of fractures in comparison to later rails.

The important point in modern stiff sections for heavy traffic is to secure a slightly higher average range of toughness and ductility in rails which are to be used in low temperatures for high-speed trains, the increased dynamic shocks under the moving wheels demanding a greater average percentage of ductility to prevent rail breakages. To raise the mean ductility, it has been found necessary in the past two years to reduce the average percentage of carbon in heavy sections to 0.50, where the phosphorus content is 0.10, for rails which are to be used where the temperatures in winter fall to zero or sometimes to 20° or 30° below. Thus, the average ductility of 100-lb. rails should be increased to a range of 12 to 18 per cent. Some heats would fall below 7 per cent., which is lower than now desired.

The fractures in rails are confined to individual heats or rails, which upon subsequent testing show a low range of ductility. The general fact that there has been a wide range in the ductility of recent Bessemer-steel rails has elicited many discussions

in this and kindred societies as to the cause of and the remedies for the reduced ductility in many heats. The sections were changed, decreasing the width of the base but making it heavier, thus increasing its percentage of metal, so that the entire section could be rolled colder than the thinner-base sections.

Fig. 1 shows the comparative ductility of several Bessemer A. R. A. 100-lb. "B" sections, each rolled from a different heat. The carbon averages 0.50, phosphorus 0.095, and manganese 0.90 to 1.00 per cent. The tests have been illustrated graphically as follows: Each blow is represented by a vertical line about one-fortieth of an inch in thickness, two blows by a line double

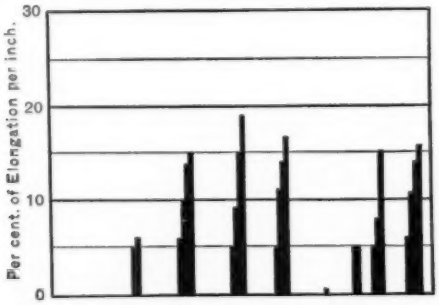

FIG. 1.—Ductility Tests on Bessemer, A. R. A. 100-lb. "B" rails.
C. = 0.51, Mn. = 0.90, P. = 0.095.
Fifth heat sheared.

that thickness, three blows by three times that thickness, and four blows by four times that thickness or one-tenth of an inch. The different steps show the percentage of elongation obtained at each blow; a double width at the top indicates that while an additional blow was required to break the butt, addit onal elongation was not produced.

One railway system has reduced the height o' drop for their standard test from 20 ft. (40,000 ft. lbs.), as formerly used, to 15 ft. (30,000 ft. lbs.). The height of drop used in this and the two succeeding tests shown in Figs. 4 and 5 was 18 ft.

The average elongation of a majority of the heats for an 18-ft. drop (36,000 ft. lbs. of energy) was from 15 to 16 per cent. (see Fig. 1), with occasional groups falling to 7 per cent. or lower. The heavy bases have proved sensitive under the drop

test, and it has not been considered prudent to use as high carbon as was expected before they were rolled. Some butts sheared over or near the supports with but a trace of elongation, which indicated at once a cold-rolled or chilled rail. When these low ranges were found, retests made from the same heat indicated that the base of the top end of the bar had been chilled in entering the rolls. This is one of the important causes of rail breakages which it was expected to eliminate by increasing the thickness of the base. However, with the less work in the straightening press for the rails on the head and base,—although there is more work on the side —it is expected that they wil show more favorable results in the track than indicated by the drop tests. The facts can be determined only by experience in service.

A wide variation in toughness and ductility has been found in basic open-hearth rails, being more pronounced in some brands than in others. These rails, where the phosphorus is often as low as 0.015 and 0.02 per cent., have shown wide ranges of ductility for different melts, and also for the same melt. There was an impression that with the low content of phosphorus and the small percentages of oxides and nitrogen in basic open-hearth steel, rails of 0.75 to 0.85 and even up to 0.90 per cent. of carbon would be safe. This has proved incorrect in practice. The ductility reduces so rapidly for the higher percentages that while the rails might pass the drop test of one blow, the total elongation of the steel in many melts was only 5 to 8 per cent., and breakages occurred in service.

In April, 1908, 3,000 tons of rails (carbon, 0.65 to 0.75; manganese, 0.90 to 1.00) were rolled, and not one has broken in the track after three winters of a high-speed service. When the carbon content is 0.70 to 0.80 per cent., with the percentage of manganese required for basic open-hearth steel, the iron seems nearly if not completely saturated. There is but little if any free ferrite left in some melts of rolled steel, and experience has shown that a number of such rails have fractured in the track. (See photomicrographs, Figs. 2 and 3.) Steel as high as 0.80 to 0.85 per cent. in carbon is so hard and brittle that it is being tested to see whether that which has been called ferrite is not really cementite.

The ingots from the basic open-hearth melts are usually large, and segregation and sometimes ferrite streaks have been important

factors in the failures of the "A" or top rails. One large railway system segregates all of the "A" rails of the ingots and uses them

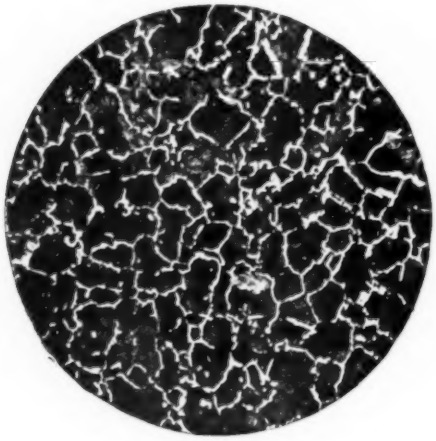

FIG. 2.—Photomicrograph, showing ferrite bounding the granulations.
C. = 0.65, Mn. = 0.62, Si. = 0.26, P. = 0.04.

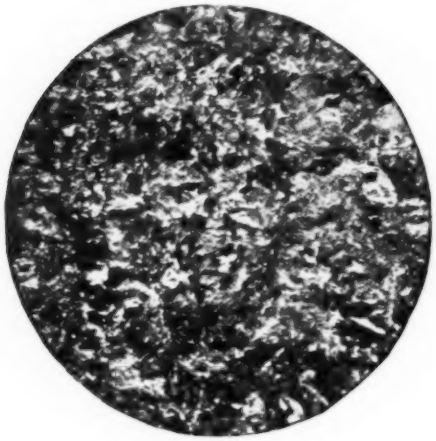

FIG. 3.—Photomicrograph, showing ferrite apparently all absorbed.
C. = 0.71, Mn. = 0.65, Si. = 0.24, P. = 0.039.

only on branch lines of light traffic. I have not taken "A" rails from large ingots for any purpose, for beside the segregation, they

often contain unwelded walls of shrinkage cavities, constituting true piped rails.

Fig. 4 shows the ductility of some basic open-hearth rails, A. S. C E. 100-lb. section, which have been rolled this year for service at low temperatures. All of the melts, with a single exception, withstood three blows of 2,000 lbs. falling 18 ft., without breaking, requiring a four h to exhaust the ductility of the metal. The lowest ductility obtained was 10 per cent. for a single melt. Tests similar to these have been used in the progressive development of basic open-hearth rails of safe qualities for high-speed

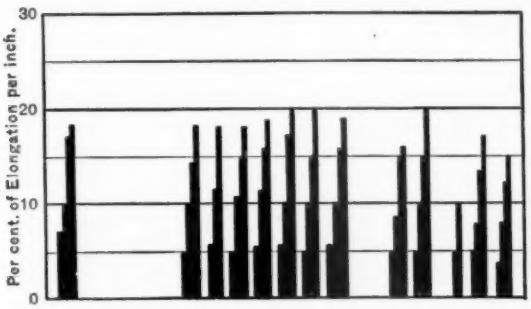

FIG. 4.—Ductility Tests on B. O. H., A. S. C.E. 100-lb. rails.
C. = 0.68, Mn. = 0.86, Si. = 0.10, P. = 0.012.

trains. The melts shown in Fig. 4 represent about 600 tons of steel.

The deflections of the butts under the first drop of 18 ft. ranged from $1\frac{1}{8}$ to $1\frac{3}{8}$ ins. The ductility of a butt which shows a deflection of only $1\frac{1}{8}$ ins. on the first blow would usually be under or near 15 per cent. Those deflecting $1\frac{1}{4}$ to $1\frac{3}{8}$ ins. would have a ductility of 15 to 20 per cent. The butts, with a single exception, have a ductility ranging from 15 to 20 per cent., the average being about 18 per cent. This is considered, and has proved to be sufficient for high-speed trains where the temperature in winter falls sometimes to 20° below zero. Should it be desired to lessen the percentage of ductility in order to make the rails slightly stiffer for greater resistance to abrasion, the carbon could be increased three to five points. Such rails would have a sufficient factor of safety for slow trains and for use in large yards where

TABLE I.—ELONGATION AND DUCTILITY TESTS OF RAILS.

Section, Dudley 6-in., 100-lb. Rail (moment of inertia = 48.5 ins.⁴); Ferro-Titanium Steel.
Rolled March 29, 1910, L. S. Co., Buffalo. Height of Drop = 17 ft.

Heat No.	No. of Blows.	Total Deflection after Blow, ins.	Length of Original Inches after Blow.							Remarks.
			1.	2.	3.	4.	5.	6.	Total.	
16256*	1	3.4	1.06	1.05	1.07	1.06	1.07	1.05	6.35	Head, web and base solid.
	2	6.3	1.10	1.10	1.11	1.11	1.11	1.09	6.60	" " " " "
	3	9.8	1.11	1.11	1.14	1.13	1.14	1.11	6.75	" " " " "
	4	11.3	1.14	1.14	1.15	1.16	1.16	1.13	6.86	" " " " "
	5	15.2	1.19	1.20	1.22	1.19	1.19	1.15	7.13	
16257	1	1.5	1.03	1.05	1.06	1.07	1.06	1.07	6.33	Head, web and base solid.
	2	2.6	1.05	1.09	1.11	1.13	1.11	1.11	6.59	" " " " "
	3	3.7	1.07	1.11	1.15	1.17	1.16	1.15	6.80	" " " " "
	4	4.3	1.10	1.12	1.15	1.19	1.18	1.17	6.91	" " " " "
	5	Sheared	1.10	1.13	1.16	1.20	1.18	1.17	6.93	
16258	1	1.4	1.03	1.05	1.05	1.08	1.06	1.06	6.33	Head, web and base solid.
	2	2.5	1.06	1.10	1.11	1.12	1.10	1.10	6.58	" " " " "
	3	Broke	1.07	1.11	1.12	1.15	1.11	1.11	6.68	" " " " "
16259	1	1.4	1.03	1.04	1.05	1.06	1.06	1.08	6.31	Head, web and base solid.
	2	2.5	1.05	1.09	1.10	1.11	1.10	1.11	6.58	" " " " "
	3	3.5	1.07	1.12	1.15	1.18	1.17	1.16	6.83	" " " " "
	4	Broke	1.07	1.12	1.16	1.19	1.17	1.16	6.86	" " " " "
16261	1	1.5	1.05	1.01†	1.10	1.07	1.07	1.05	6.34	Head, web and base solid.
	2	2.7	1.06	1.04	1.13	1.12	1.12	1.10	6.55	" " " " "
	3	Broke	1.11	1.10	1.20	1.15	1.15	1.12	6.85	" " " " "

*Specimen from Heat No. 16256 was stamped in side of head and placed on supports on its side. (Lateral moment of inertia = 8.5 ins.⁴.)
† Note second inch in Heat No. 16261; measurement is correct.

great resistance to abrasion on curves is a desideratum. The metal would flow slightly until a thin layer was cold-rolled by the passing wheel loads, when the flow would stop.

Fig. 5 shows Bessemer heats containing 0.50 per cent. carbon and 0.07 per cent. phosphorus, which were intended to have a ductility of about 15 per cent. A single heat reduces to 7 per cent., although it required a second blow to break the butt. The Bessemer rails, owing to the greater content of phosphorus, oxides, and nitrogen, show a greater tendency to irregular low ranges of ductility than the basic open-hearth rails made in a manner similar to those represented in Fig. 4. One Bessemer heat in Fig. 5 shows a maximum

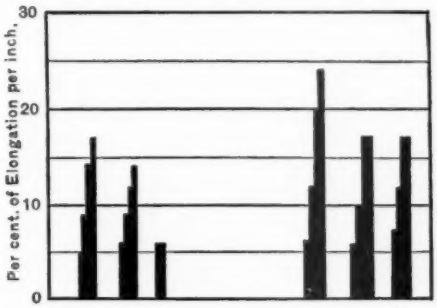

FIG. 5.—Ductility Tests on Bessemer, A. S. C. E. 100-lb. rails. C. = 0.51, Mn. = 0.97, P. = 0.071.

elongation of 24 per cent. This is not unusual in rails of about 0.50 carbon and 0.07 phosphorus, but it is higher than can be obtained in most heats, while another heat may drop to 7 or 8 per cent. The use of ferro-titanium in the steel to take up a greater percentage of the oxides and also a part of the nitrogen, has rendered it possible to raise the average ductility in Bessemer rails to a point where it requires two or more blows to exhaust the ductility, and sometimes a fourth or fifth to break the butt. Many thousand tons of Bessemer rails of 0.50 carbon and 0.095 phosphorus, with the addition of ferro-titanium, have been rolled in the past two years and hardly a breakage occurred during the past two winters. At one location where 5,000 tons were laid under heavy traffic, a single fracture did not occur in sixteen months' service, where previously in ordinary Bessemer rails of the

same section and general composition, the fractures were more frequent than considered permissible and the rails were replaced.

Table I shows five elongation and ductility tests. The first specimen, Heat No. 16256, was tested upon the side with the flange up, and while the lateral moment of inertia is 8.5 compared to 48.5 ins.^{4} for the vertical, the first deflection was only 3.4 ins., partly due to the fact that the butt bent around the curved striking face of the die instead of only its point of contact, as it would for a blow on the head. The upper edge of the flange, which was under compression, deformed by buckling under the point of the blow rather than by upsetting the metal. The butt was not broken by five blows. The elongation on the under side of the head is given for each blow. The total for the fifth blow was 1.13 ins.

The specimen from Heat No. 16257 sheared instead of breaking on the fifth blow, the maximum ductility being 20 per cent. in the fourth inch. The elongation in six inches in each of the four last specimens ranged from 0.80 to 0.85 in. before the metal fractured. The third specimen gave a total elongation of only 0.68 in., which provides, however, a large factor of safety. The low percentage of elongation in the second inch of the last butt, Heat No. 16261, is doubtless due to an accidental bruise in putting the butt in, or in taking it out of the supports for measurement. The head, web, and base were solid in all tests. These heats were intended to have a range of ductility of 15 to 18 per cent., which has been secured in all of the specimens.

Eighty-pound rails of the same grade of steel as the 100-lb. rails have practically the same ductility, which is exhausted with a fewer number of blows owing to the smaller mechanical properties of the section. Given rails of the same grade of steel, the deflections of the different sections closely follow the mechanical properties; and when the chemical composition has been ascertained for one it may be determined and prescribed for other sections with different mechanical properties by intelligently comparing the moments of inertia and the energy expended in producing given deflections.

The physical properties of the different sections can therefore be compared and their chemical composition adjusted from the results obtained under the Manufacturers' standard drop-testing machine.

TESTS OF STEEL AND WROUGHT-IRON BEAMS.

By H. F. Moore.

Introduction.

There are available but little experimental data on the strength of steel and wrought-iron beams of the usual structural shapes. The possibility of failure of such beams by twisting action or by sidewise buckling is not considered in the derivation of the flexure formulas commonly used in computing the strength of such beams. However, this possibility has been recognized by engineers and mathematicians, and various attempts have been made to establish formulas which take these actions into account. The experiments described before this Society by Professor Marburg* in 1909 furnish a most striking demonstration of the failure of beams by sidewise buckling and by twisting action.

During the past year there has been carried on in the Laboratory of Applied Mechanics of the University of Illinois, a series of tests of iron and steel beams, principally small I-beams. The principal object of these tests was to investigate twisting action and sidewise buckling of test beams of various lengths, and to determine the magnitude of the direct bending stresses which were developed in the beams at failure. The results here presented should be taken as preliminary and tentative, and not in any sense as conclusive. In view of the general interest in the strength of beams, it seemed worth while to present at this time a description of the methods of testing used and a brief discussion of the preliminary results obtained. It is planned to continue the tests.

All of the experimental work of these tests at the University of Illinois was performed under the immediate supervision of the writer. Acknowledgment is hereby made of the assistance of Messrs. F. J. Weston and W. E. Deuchler, of the class of 1910, of the University of Illinois.

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* *Proceedings*, 1909, Vol. IX, pp. 378–407.

TEST PIECES.

The principal tests were made on 8-in. 18-lb. I-beams, tested over various spans without side restraint. The following beams were tested:

Two beams with span of 5 ft.
Two beams with span of 7.5 ft.
Two beams with span of 10 ft.
One beam with span of 20 ft.

Tests were also made as follows:

One pair of 8-in. 18-lb. I-beams, bolted together at four points, with cast-iron separators, span 10 ft.
Two 8-in. 18-lb. I-beams, span 10 ft., compression flange restrained from sidewise buckling.
Two 8-in. 25¼-lb. I-beams, span 10 ft., no side restraint.
One piece of wrought-iron bridge post tested as a beam, span 10 ft. Post made up of two 8-in. channels double-laced together. Test made with lacing horizontal.
One beam, same as last except that lacing had been cut off.
One built-up wrought-iron girder, 17½ ins. deep, span about 13 ft., angle-iron stiffeners at ends.
One beam, same as last except that stiffeners had been cut off.
One built-up wrought-iron girder, 24 ins. deep, span 14 ft. 2¾ ins., angle-iron stiffeners at ends.
One beam, same as last except that stiffeners had been cut off.

Table I shows results of the tension tests of material from the beams. Each specimen was cut from the least stressed part of a beam. The table shows the location of each test specimen in the beam.

APPARATUS AND TESTS.

Some of the tests were made on an Olsen 200,000-lb. testing machine, fitted with a long table for transverse tests, and other tests were made on a 600,000-lb. Riehlé testing machine. All the beams except the 24-in. built-up girders were loaded at the third-points of the span. The 24-in. girders were loaded at two points, each 12 ins. from the center of the span. Fig. 1 shows the method of loading, which was planned to give as great freedom of motion to the test beam as possible. In the case of the pair of beams with separators, the bridge posts, and the built-up girders, rollers were used in place of the spherical bearings. Fig. 2 shows the arrange-

TABLE I.—RESULTS OF TENSILE TESTS OF MATERIAL FROM TEST BEAMS.

Beam No.	Material.	Test piece from	Yield Point, lbs. per sq. in.	Ultimate Strength, lbs. per sq. in.
1	Steel..	Flange	33,800	60,900
		Junction of flange and web	40,500	61,100
		Web	39,900	65,900
2	Steel..	Flange	34,200	61,500
		Junction of flange and web	34,100	59,700
		Web	35,100	55,100
3*a*	Steel..	Flange	30,200	51,300
		Junction of flange and web	32,000	58,300
		Web	33,600	56,400
3*b*	Steel..	Flange	34,600	62,600
		Junction of flange and web	32,400	60,200
		Web	39,900	56,300
4	W. Iron	No specimens cut from beam	.....	.....
5	Steel..	Flange	34,100	59,700
		Junction of flange and web	35,700	61,700
		Web	36,300	60,000
6	Steel..	Flange	46,200	64,500
		Junction of flange and web	39,800	62,000
		Web	36,400	64,300
7	Steel..	Flange	46,700	59,400
		Junction of flange and web	31,300	59,000
		Web	32,000	61,100
8	W. Iron	No specimens cut from beam	.....	.....
9	Steel..	Flange	37,000	59,200
		Junction of flange and web	33,600	54,200
		Web	34,400	55,300
10	W. Iron	Same material as in Beam 11	.....	.....
11*a*	W. Iron	Flange	35,200	46,800
		Web	35,300	48,500
11*b*	W. Iron	Flange	35,500	47,400
		Web	33,300	44,500
12	Steel..	Flange	37,000	59,000
		Junction of flange and web	34,800	58,000
		Web	34,100	54,000
13	Steel..	Flange	34,600	56,500
		Junction of flange and web	32,100	58,200
		Web	34,600	57,500
14	Steel...	Same material as in Beam 6	.....	.....
15	Steel...	Same material as in Beam 6	.....	.....
16	W. Iron	No specimens cut from beam	.....	.....
17	W. Iron	No specimens cut from beam	.....	.....
18	Steel..	Flange	41,750	56,600
		Junction of flange and web	39,400	55,100

ment of apparatus for the test of the light 8-in. I-beams with the compression flange restrained. The beam is so loaded as to bring the bottom flange in compression, and sidewise motion of this flange is prevented by guide beams firmly clamped to the weighing table of the testing machine.

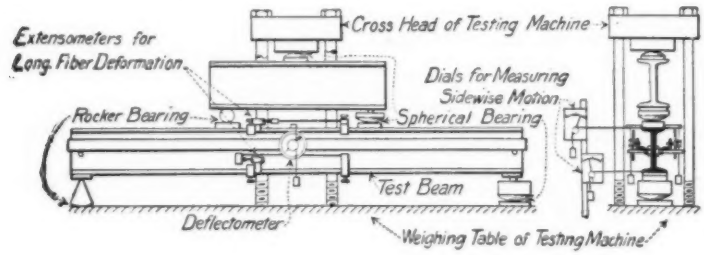


FIG. 1.—Beam Tested without Sidewise Restraint.

Measurements of deflection, longitudinal fiber deformation, and sidewise motion of the beam were made. Fig. 1 shows the arrangement of instruments and machine. The deflection was measured by means of wire-wound measuring dials reading to one five-thousandth of an inch. Measurements were made on both

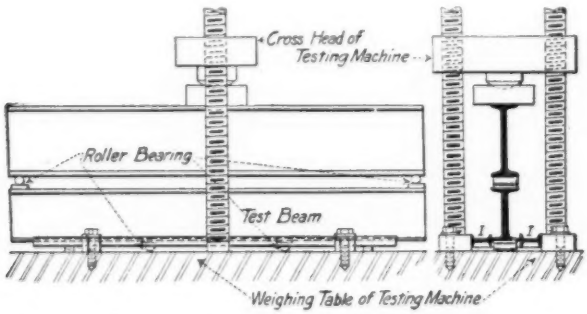


FIG. 2.—Beam with Compression Flange Restrained.

sides of the beam, and the dials were supported as shown in Fig. 1. Longitudinal fiber compressions and extensions were measured near the top and bottom fibers by means of Ames test gages, which were read by estimation to one ten-thousandth of an inch. Sidewise motion of the beam was measured at various points from standards resting on the floor of the laboratory. In some

cases Ames dials were used to measure sidewise motion, and in other cases wire-wound measuring dials were used. In the tests of I-beams with the compression flange restrained, sidewise motion was not measured. In nearly all tests, after each load had been applied, the load on the beam was reduced to a small amount (usually 1,000 lbs.), and then a load was applied slightly greater than the former load. This procedure was continued until the elastic limit had been considerably exceeded. From the readings of the instruments, both deformation under load and permanent set after load could be determined.

DATA AND RESULTS.

Table II gives the moduli of rupture computed from the results of the various tests and adjusted to values for steel of 60,000 lbs. per sq. in. ultimate strength. Table II also gives the values of fiber stress at the elastic limit of the beam as computed from the data of the tests and adjusted to values for steel of 60,000 lbs. per sq. in. ultimate strength. The method of adjustment of stresses to values for steel of 60,000 lbs. per sq. in. ultimate, was to multiply the observed value by 60,000 and to divide the product by the ultimate strength of the steel in the flange as given by tension tests of specimens cut from the beam. It is recognized that this method of adjustment is somewhat empirical, but it was judged that a fairer comparison between different beams could be made if such allowance was made for the difference in strength of material, than if no such adjustment was made. The ultimate strength was used as the basis of adjustment, as it is determined with a greater degree of accuracy than is the yield point, and as it is less affected by variations in thickness of flange. For the wrought-iron bridge posts, this adjustment is at best a rough one, but seems to be the best possible. The elastic limit of the beam was taken as that stress at which the departure of the plotted stress-deformation curve from a straight line was first detected. In general, for each beam the elastic limit recorded in Table II is the mean of the elastic limits determined from (1) the stress-deflection curve, (2) the stress - compression-of-upper-fiber curve, and (3) the stress - elongation-of-lower-fiber curve. A brief discussion of the significance of the elastic limit determined in this

TABLE II.—RESULTS OF TESTS OF STEEL AND WROUGHT-IRON BEAMS.

Beam No.	Material.	Depth, ins.	Weight, lbs. per ft.	Span.	Loading and Special Features.	Elastic Limit. Observed, lbs. per sq. in.	Elastic Limit. Corrected,* lbs. per sq. in.	Modulus of Rupture. Observed, lbs. per sq. in.	Modulus of Rupture. Corrected,* lbs. per sq. in.	Manner of Failure.	Sidewise Motion at Fiber Stress of 16,000 lbs. per sq. in. Deflection, ins.	Sidewise Motion at Fiber Stress of 16,000 lbs. per sq. in. Twist, degrees per in. of length.
9	Steel . . .	8	18	5′ 0″	Third point, no side restraint.	30,850	30,450	38,400	37,900	Sidewise buckling of comp. flange.	....	....
12	Steel . . .	8	18	5′ 3″	" "	28,000	29,300	37,800	39,500	Twist of web.	....	0.0014
14	Steel . . .	8	18	7′ 6″	" "	27,700	26,700	36,500	35,200	Sidewise buckling of comp. flange.	....	....
15	Steel . .	8	18	7′ 6″	" "	28,000	27,000	36,800	35,400	"	....	....
1	Steel . . .	8	18	10′ 0″	" "	23,000	22,700	36,000	35,500	"	....	....
2	Steel . . .	8	18	10′ 0″	" "	22,600	22,300	32,800	32,400	"	....	....
6	Steel . . .	8	18	20′ 0″	" "	21,400	20,600	28,100	27,100	Sudden sidewise buckling	0.046	0.0022
3	Steel . . .	8	18	10′ 0″	Third point, two beams with separators.	26,000	27,000	39,200	40,700	Sidewise buckling.	0.036	0.0003
13	Steel . . .	8	18	10′ 0″	Third point, comp. flange restrained sidewise (Fig. 2).	23,600	24,800	41,000	43,000	Gradual sag in plane of load.	0.021	0.0022
18	Steel . . .	8	18	10′ 0″	Same as Beam 13.	26,400	28,200	47,000	50,200	Gradual sag in plane of load.	....	....
5	Steel . . .	8	25.25	10′ 0″	Third point, no side restraint.	30,000	29,900	39,800	39,700	Sidewise buckling of comp. flange.	0.026	....
7	Steel . . .	8	25.25	10′ 0″	" "	28,000	28,300	36,500	37,000	Sidewise buckling of comp. flange	0.019	0.0020
10	W. Iron	8	14.33	10′ 0″	Load 3 ft. 6 ins. from each end support. Two channels laced together.	24,100	30,750	36,200	46,200	Gradual sag in plane of load.	0.005	Very slight.
11	W. Iron	8	14.33	10′ 0″	Same as Beam 10, except that lacing was cut off.	23,300	29,600	33,000	42,000	Sidewise buckling	0.058	Very slight.
4	W. Iron	17.5	Built-up	13′ 7½″	Third point, no side restraint. End stiffeners used.	25,600	....	35,000	....	Local crippling under load. Twist of web.	0.048	0.0044
8	W. Iron	17.5	Built-up	12′ 10½″	Same as Beam 4, except no end stiffeners.	18,800	....	31,700	....	Same as Beam 4	0.030	0.0079
16	W. Iron	24	Built-up	14′ 2¾″	Loads 12 ins. each side of center, no side restraint. End stiffeners used.	18,600	....	24,200	....	Gradual twist of web . . .	0.095	0.0034
17	W. Iron	24	Built-up	14′ 2¾″	Same as Beam 16, except no end stiffeners.	14,800	....	28,900	....	Sudden twist of web	0.067	0.0055

*Corrected values are obtained by multiplying the observed values by $\frac{60{,}000}{\text{Ultimate tensile strength of material in flange}}$

way is given later. Fig. 3 shows typical curves obtained from the data of a test.

Sidewise Motion of Beams.—During the tests considerable sidewise motion and twisting action were observed at stresses below the elastic limit. In Table II have been tabulated the sidewise deflection and the twist of the beams under a calculated fiber stress of 16,000 lbs. per sq. in. These results are less precise than the results depending on measurement of deflection or fiber deformation. The very small amount of twist in the 8-in. I-beam with a 20-ft. span is worthy of note, as is the very small sidewise deflection and twist in the case of the two channels laced together. The built-up beams, with their broad flanges and thin parts, showed

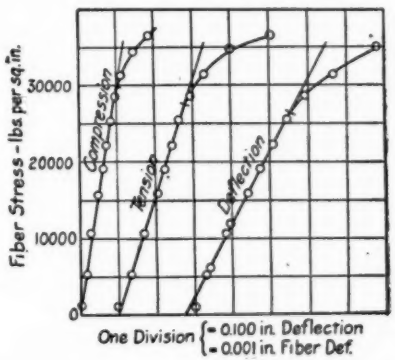


FIG. 3.—Results of Typical Test of a Beam.

relatively large twisting action. The manner of final failure may be seen from Table II.

Moduli of Rupture of Beams.—An examination of Table II, in connection with Table I, will show that even in short beams the modulus of rupture exceeded but slightly the yield point of the material as determined by tension tests of specimens. In every case the value of the modulus of rupture was much less than the ultimate tensile strength of the material. In the case of Tests 13, 18, and 10, in which there was restraint against sidewise motion, the beams failed by gradual bowing in the plane of the load, and the failure was very slow. In Beams 1, 2, 3, 5, 6, 7, 9, 11, 14, and 15, the failure was by sidewise buckling of the compression flange, and was, in each case, more sudden than any of the

bowing failures. It should be noted that Beams 11 and 3 failed by sidewise buckling, though they were partly restrained against sidewise motion. Beam 6 (20-ft. span) failed very suddenly indeed, the failure resembling the buckling of a thin steel straight-edge under longitudinal compression. In Beams 4, 8, 12, 16, and 17, the final failure was by twist of web, and was in general sudden. It will be noted that in the cases of failure by twist of web, the beams were comparatively short and deep.

Effect of Length of Span.—Fig. 4 shows the results of the tests plotted with values of modulus of rupture as ordinates and

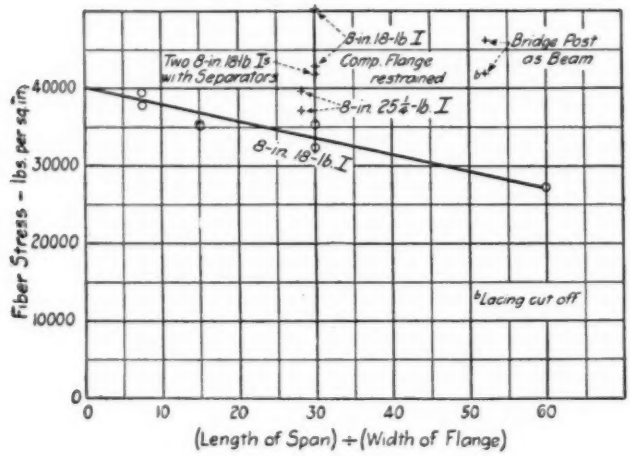


FIG. 4.—Moduli of Rupture of Beams.

values of length of span divided by width of flange as abscissas. Fig. 5 shows a similar plot with values of stress at elastic limit of beam as ordinates. In both these curves the values for 8-in. 18-lb. I-beams are designated by circles.

Formulas for failure of beams by lateral buckling have been worked out by Michell,* by H. D. Hess†, and in the Cambria Steel Handbook. Experiments to determine the effect of the length of span have been performed by Christie‡ and Guy.§ The results

* *American Machinist*, March 10, 1906; article by Reissner. *Philosophical Magazine*, 1890, p. 298.

† *Proceedings, Engineers' Club of Philadelphia*, April, 1909.

‡ *Pencoyd Handbook* (1898 ed.), p. 23.

§ Guy, "*Flexure of Beams*," Van Nostrand.

of Christie's tests led to the adoption of stress values for the design of beams without side restraint, which are given in the Pencoyd and the Carnegie handbooks. Curve 1 in Fig. 6 was plotted from these stress values. The reported result of tests made at the Pencoyd Iron Works is also shown. Guy's experiments were all made on small wooden beams. Michell's formulas contain constants involving the stiffness of beams under torsion, and such constants are not at present available for I-beams. The formulas in the Cambria Steel Handbook and those derived by Hess are based on the Rankine-Gordon column formula. The constants in Hess's formulas have been modified by the writer for third-point loading, and Curves 3 and 4 in Fig. 6 have been plotted from the

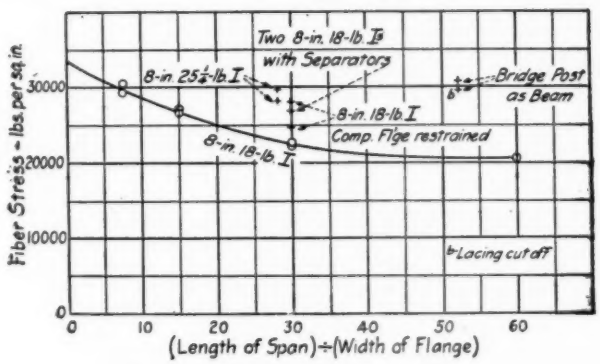


FIG. 5.—Elastic Limits of Beams.

modified formulas. In the same figure, the mean values obtained in the Illinois tests for moduli of rupture of light 8-in. I-beams are shown by the heavy line. While these tests are altogether too few to establish any law, they show that the strength of beams without sidewise restraint is not independent of the length of span, and they give some ground for belief that beams designed by the handbook formulas or by Hess's results are safe as regards failure by lateral buckling.

Effect of Weight of Beam.—In Figs. 4 and 5 are plotted the results of tests of two heavy 8-in. I-beams. These two beams developed at failure higher computed stresses than did the corresponding light I-beams. It would seem reasonable to suppose that in the case of a heavy beam of stocky section, the heavy web

would materially assist the compression flange in its resistance to sidewise buckling. In a beam of light section the compression flange would receive but little assistance from the web against sidewise flexure.

Twisting Action in Beams.—Table II shows the existence of considerable twisting action in the beams under comparatively low loads. One of the short-span 8-in. I-beams and all the built-up wrought-iron girders finally failed by twisting action. It was impossible to determine in these beams whether twisting action was the primary cause of failure. Definite data on the resistance of "I" sections to twisting are altogether lacking, but before

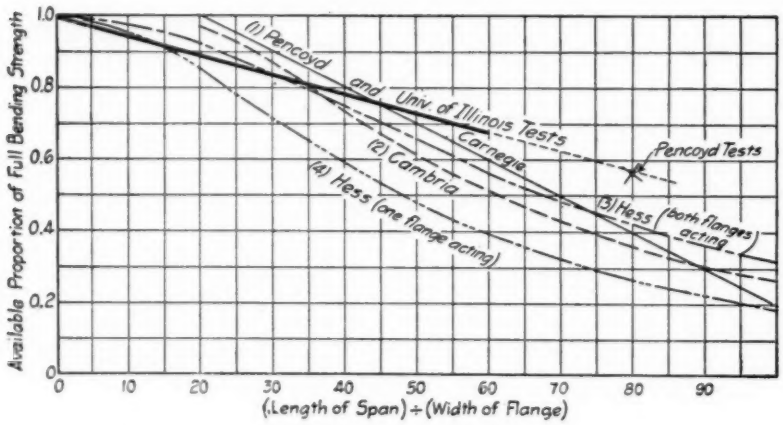


FIG. 6.—Resistance of Beams to Lateral Buckling.

serious damage could be done by torsion the deformation would be considerable, and lateral restraint would exert considerable influence in resisting failure by twisting action. The effect of twisting action in causing beams to assume such deformed shapes that they are rendered less able to resist bending action, seems an interesting field of study. In the tests of the built-up girders, the effect of the end stiffeners in resisting twisting failure is uncertain. The end stiffeners seem to have diminished twisting under working loads. These stiffeners did not fit the flanges of the beams very snugly.

Significance of Elastic Limit.—The method of determining the elastic limit of the test beams has been described. It may be

added that the first noticeable permanent set occurred, in general, at stresses slightly higher than the elastic limit tabulated. The elastic limit thus determined may be more properly called the limit of proportionality of stress to deformation, or more briefly, the limit of proportionality. This limit of proportionality is sometimes called the "true" elastic limit, and is frequently regarded as a measure of the load-carrying capacity of a member or structure. The writer wishes to call attention to several considerations which bear on this point.

First, the *absolute* value of this limit for any member or structure cannot, in general, be determined even by the most careful measurements of deformation and load. It has been the experience of experimenters that any additional refinement of measurements in stress-deformation tests results in the detection of the limit of proportionality at a stress lower than that determined by the less refined methods of measurement. Perhaps the thermo-electric apparatus used by Turner* and Rasch† for measuring deformation is the most delicate yet employed, and both of these experimenters showed the existence of a limit of proportionality at stresses far lower than those determined by extensometer measurements as ordinarily made. There seems no reason to doubt that if more delicate instruments had been used in these beam tests, the limit of proportionality would have been detected at lower stresses than those tabulated.

Second, members and structures become more and more nearly perfectly elastic if subjected to repeated stresses in the same direction, even if these stresses are so far beyond the limit of proportionality that there is a small but well-defined permanent set upon release of the load. Fig. 7 shows the result of loading Beam 2 several times to a stress well beyond the elastic limit. The first load applied to the beam produced considerable permanent set, and during the application and release of load, considerable energy was lost, presumably in heat. This energy is shown by the shaded area to the left of the figure. During the second cycle of loading and release, much less energy was lost, as shown by the central shaded area; and during the third cycle, the

* *Transactions, American Society of Civil Engineers*, January, 1902

† *Proceedings, International Association for Testing Materials*, No. 11, August 4, 1909, Article VII.

beam behaved as if almost perfectly elastic. Similar results were obtained with Beams 3, 4, 5, 6, 7, 8, and 10. It should be noted that the above results would not be obtained if the direction of the load were reversed.

Third, many structural members in the process of manufacture and erection are stressed locally beyond this limit of proportionality; for example, I-beams are not infrequently cold-straightened to bring them into proper alignment. Very many such

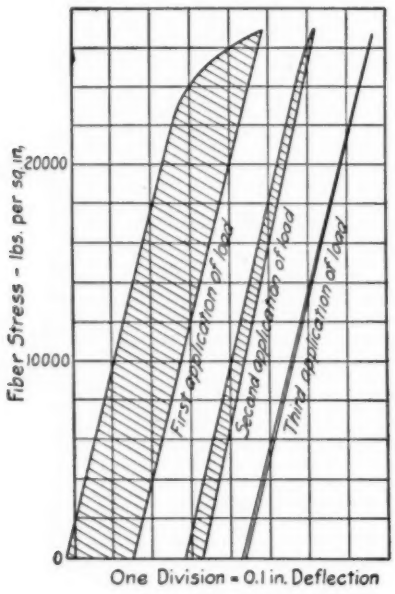


FIG. 7.—Effect of Repeated Loads on Beams.

members have proven entirely satisfactory under severe service, though in many cases the stress due to load must have been added to local stress due to manufacture or erection. There are undoubtedly many steel structures giving satisfactory service, though locally stressed beyond the limit of proportionality or "true" elastic limit.

In view of the above considerations, the writer feels that it is not altogether certain that the limit of proportionality of a structural member is a satisfactory criterion of its load-carrying capacity.

Effect of Sidewise Restraint of Beams.—In Figs. 4 and 5 are plotted the results of tests for elastic limit and for modulus of rupture of several beams in which the compression flange was under restraint, which restraint was more or less effective against sidewise buckling. The method of restraint of the beams marked "compression flange restrained" is shown in Fig. 2, and in these beams and the bridge post tested as a beam with the lacing in place, the restraint was particularly effective. One effect of sidewise restraint seems to be to raise the modulus of rupture nearly to or slightly above the yield point of the material in tension and to cause failure to take place slowly. This may be seen by an examination of Table II in connection with Fig. 4. The effect of sidewise restraint upon the elastic limit of beams seems to be less marked than upon the modulus of rupture, as may be seen by comparing Fig. 4 with Fig. 5. It seems quite probable that if very delicate instruments had been used, the elastic limit of the beams most effectively held against sidewise motion would have been found to be but little higher than the elastic limits of the unrestrained beams.

The effectiveness of sidewise restraint of a beam in raising the allowable working stresses would seem to depend on whether the modulus of rupture or the elastic limit (limit of proportionality of stress to deformation) is considered the measure of the load-carrying capacity of the beam.

DISCUSSION.

Mr. Lanza. MR. GAETANO LANZA.—I should like to ask the writer of the paper with respect to that straight line on his diagram representing the modulus of rupture, whether he has evidence that it generally represents the tests, or whether he merely drew it through the points.

Mr. Moore. MR. H. F. MOORE.—I know of no reason why that line should be a straight one. I merely drew it to show the results of our tests, but it also fitted very nicely the results of the tests at the Pencoyd Iron Works.

Mr. Marburg. MR. EDGAR MARBURG.—Since I-beams are used chiefly in buildings in which the loads are either static or essentially so, the most important consideration from a practical standpoint would seem to be the determination of the minimum static load under which a beam will yield progressively, however gradually, to failure. It is also desirable that reliable data from tests on full-size beams should be obtained as to their ultimate strength under repetitive loading without impact. Unfortunately, tests of either kind are very time-consuming. Until such investigations are made, however, the practical significance of the elastic limit or yield point in bending, as variously defined and determined under a single application of a gradually increasing load, must remain as doubtful as it is at present.

I should like to ask Mr. Moore whether he observed the elastic limit as well as the yield point in the tension tests on the specimens cut from the beams, and if so, in what general relation they stood to each other.

Mr. Moore. MR. MOORE.—As yet we have made no experiments as to how much the elastic limit differs from the yield point. A large number of specimens are awaiting further tests for the determination of the yield point and the elastic limit.

Mr. Souther. MR. HENRY SOUTHER.—I do not know that much more can be added to what has been shown. It has come within my experience two or three times to test beams tied together, as described by Mr. Moore, and the results have not been in accordance with what was expected. There have been compound stresses due

to twisting and distortion of one kind or another that have made me feel that a large factor of safety is a good thing, and that the calculated elastic limit should not be approached too closely. Such beams do not seem to act together, but behave rather like a badly matched team of horses. **Mr. Souther.**

MR. E. L. HANCOCK.—I should like to ask how much time elapsed between the first overstrain of the beam and the subsequent loading. **Mr. Hancock.**

MR. MOORE.—I should say that the average time in this case was two or three minutes. No attempt was made to study the effect of rest between loadings. **Mr. Moore.**

MR. MONT SCHUYLER.—Referring to Mr. Marburg's remarks on what is evidently a flowing of certain materials under a static uniform load, in the Testing Laboratory of the City of St. Louis experiments have been made on concrete cylinders with this object in view. Certain specimens which had successfully carried 100,000 lbs. without giving evidence of failure were loaded to 50,000 lbs., and this load maintained for several days. In one particular case where the beam had been kept floating for upwards of 30 minutes by a gradual advance of the crushing head, the machine was left untouched for 36 hours; micrometer readings were then taken, and compared with those taken at the beginning of this period. The specimen had shortened 0.002 in. and the balancing position of the poise indicated a load of 47,600 lbs. Specimens 8 ins. in diameter and 16 ins. long were used. **Mr. Schuyler.**

MR. J. M. PORTER.—I have made a number of tests on large beams, and have just completed one on a plate girder, the results of which may be of interest. The girder was 36 ins. deep with a $\frac{7}{16}$-in. web plate and 4 by 6 by $\frac{5}{8}$-in. flange angles, and was tested on a span of 19 ft. 6 ins. While the results of this test have not been fully computed, yet I can say that the observed elastic deflection of the girder agreed with its computed deflection within 13 per cent. An endeavor was made to determine the stress in the stiffeners by means of delicate measurements, but micrometers reading to one ten-thousandth of an inch showed no indications of stress. The girder failed through the rupture of the lower flange angles through the rivet holes. The girder was loaded symmetrically at two points about 4 ft. apart. The top flange was supported laterally only by such resistance as was developed by friction at the points of application of the loads. **Mr Porter.**

STRENGTH OF STEEL FROM I-BEAMS.

By E. L. Hancock.

The writer had the opportunity to make tests of steel from standard beams during the past year. The investigations of Professor Edgar Marburg, reported at the last meeting of the Society, showed considerable variation in the strength of the steel from the web, flange, and root of web. Few tests were made,

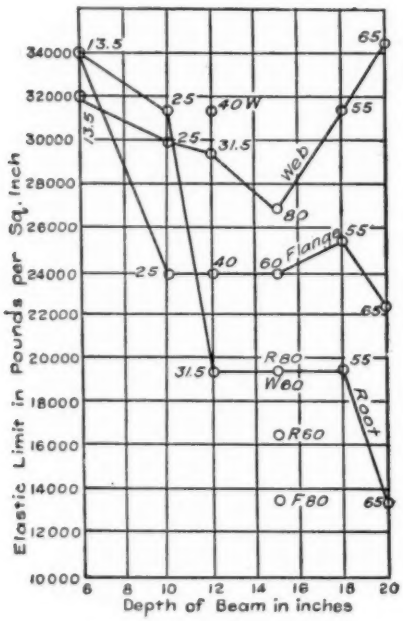


Fig. 1.—Variation of Elastic Limit with Depth of Beam.

however, on steel from standard I-beams, the investigation being confined principally to Bethlehem beams.

The tests reported below were made on pieces cut from standard I-beams varying in size from 6 ins., 13.5 lbs., to 20 ins., 65 lbs., and on pieces cut from three Bethlehem beams. Crop ends of standard beams were furnished by the Eastern Bridge

and Structural Company of Worcester. The Bethlehem material was bought on the market. The test pieces were prepared and tested at the Worcester Polytechnic Institute. The specimens were cut from the middle of the web (designated by W), the root

TABLE I.—TESTS OF STEEL FROM STANDARD I-BEAMS.

Beam. Mark.	Beam. Depth, ins.	Beam. Weight, lbs. per ft.	Specimen cut from	Elongation in 8 ins., per cent.	Reduction of Area, per cent.	Elastic Limit, lbs. per sq. in.	Maximum Strength, lbs. per sq. in.	Location of Fracture.	Appearance of Fracture.
A	6	13.5	Web	18.7	46	32,000	68,300	3rd in.	Silky.
			Flange ...	29	49	34,000	65,300	3rd in.	"
			Root	29	50	34,000	64,300	4th in.	"
B	10	25	Web	28.3	61.5	30,000	56,500	1st in.	Granular and Silky
			Flange ...	28.1	63	25,500	54,600	Center	
			Root	25	56.3	33,000	58,600	2nd in.	
C	10	25	Web	20.2	39.2	24,750	72,300	2nd in.	Granular and Silky.
			Flange ...	34.4	48.8	26,600	61,200	4th in.	
			Root	25	54.2	27,000	66,400	3rd in.	
D	12	31.5	Web	31.3	54	29,500	61,800	4th in.	Granular and Silky.
			Flange ...	26.6	50.6	22,500	59,500	3rd in.	
			Root	25	53	19,500	63,700	2nd in.	
E	12	40	Web	31.2	56.5	31,500	59,800	2nd in.	Granular and Silky.
			Flange ...	21.9	51.2	24,000	62,500	4th in.	
			Root	31.2	55.6	19,500	61,500	2nd in.	
F	12	40	Web	30	58.7	28,500	62,200	2nd in.	Granular and Silky.
			Flange ...	18.7	55	18,700	62,200	1st in.	
			Root	31	58	24,000	61,700	2nd in.	
G	15	42	Web	28.2	46.7	31,500	68,700	3rd in.	Granular and Silky.
			Flange ...	.....	.....	29,900	.....	.....	
			Root	26.6	48	22,500	56,000	4th in.	
H	15	60	Web	29	58.2	19,500	53,300	3rd in.	Granular
			Flange ...	29	60.8	24,000	55,200	3rd in.	"
			Root	29	59.2	16,500	53,800	2nd in.	"
I	15	80	Web	36	57.8	27,000	54,300	3rd in.	Granular
			Flange ...	31	61.2	19,500	55,300	2nd in.	"
			Root	33	56.9	19,500	55,000	4th in.	"
J	18	55	Web	28.5	53	31,500	55,800	2nd in.	Granular
			Flange ...	29	55.6	25,500	56,700	3rd in.	"
			Root	28.5	57.5	19,500	60,400	4th in.	"
K	20	65	Web	28.5	45.3	34,500	62,700	2nd in.	Granular and Silky.
			Flange ...	28	52.5	22,500	63,800	3rd in.	
			Root	30	54.3	13,500	64,000	2nd in.	

of the web (designated by R), and the flange near the root (designated by F). These were very carefully prepared and finished by draw-filing. The reduced section was long enough to admit the use of the extensometer on an 8-in. gage length. The cross sections varied approximately from $1\frac{1}{16}$ in. by 1 in., to $\frac{1}{2}$ in. by 1 in.

Great care was used in inserting the test piece in the Wicksteed testing machine, in order to guard against possible eccentric load. A special type of extensometer, so arranged as to detect bending of the test piece, was used. This extensometer is a modification of the Yale-Riehlé instrument, differing principally in that it is provided with four screws for attachment to the specimen and with four micrometers for reading elongations. It is an electric-contact instrument measuring to ten-thousandths of an inch. It is made by Riehlé Brothers.

The tests were conducted with the greatest care, every precaution being taken to make all conditions of test right.

TABLE II.—TESTS OF STEEL FROM BETHLEHEM BEAMS.

Beam.			Specimen cut from	Elongation in 8 ins., per cent.	Reduction of Area, per cent.	Elastic Limit, lbs. per sq. in.	Maximum Strength, lbs. per sq. in.	Location of Fracture.	Appearance of Fracture.
Mark.	Depth, ins.	Weight, lbs. per ft.							
L	24	73	Web	25	52.8	33,000	72,600	Center	Silky.
			Flange	28	53.8	24,000	70,000	4th in.	"
			Root	28.1	57.3	22,500	67,300	3rd in.	"
M	18	48.5	Web	26.6	55.4	19,500	59,600	1st in.	Silky.
			Flange	31.3	55.7	21,000	57,300	2nd in.	"
			Root	31.3	58.5	28,500	56,200	4th in.	"
N	12	36	Web	21.9	44	31,500	72,600	1st in.	Silky.
			Flange	26.6	43.7	33,000	66,000	1st in.	"
			Root	25	51	24,000	68,400	2nd in.	"

RESULTS.

The results of the tests are shown in Tables I and II. It is to be noted that, generally, the material cut from the web shows the highest elastic limit, while that cut from the root of the web shows the lowest elastic limit. These facts are shown graphically in Fig. 1.* Figs. 2 and 3 show some of the stress-deformation diagrams.

In planning the tests it was hoped to have a complete chemical analysis of each piece tested. Owing to lack of funds, however, this was not possible. Samples from one set, K, were examined

* Acknowledgment is made to the *Engineering Record* for cuts of Figs. 1 and 2 used in this paper.—ED.

for carbon, and showed a variation in carbon of five points. The results were as follows:

Specimen.	Carbon, per cent.
KW	0.22
KF	0.27
KR	0.25

This one analysis shows that the variation of strength may be due to a difference in chemical composition. It is hoped that means

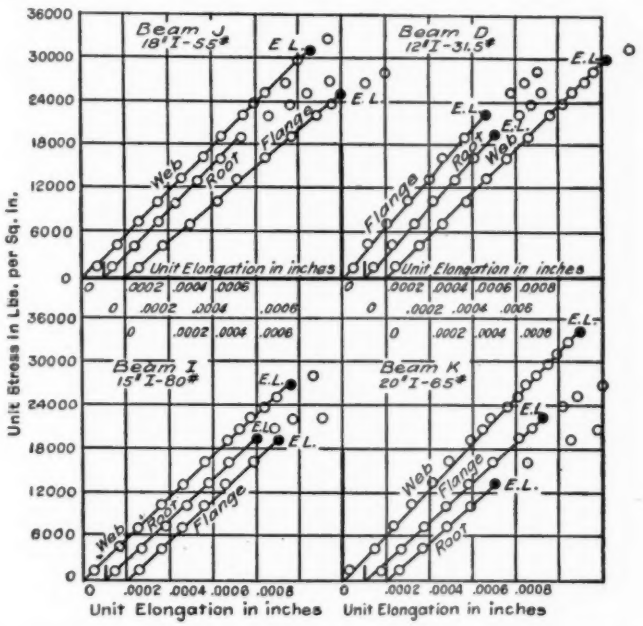


FIG. 2.—Tension Tests of Specimens Cut from Standard I-Beams.

may still be provided whereby a complete chemical analysis of each specimen may be made.

A small piece was cut from the end of each test specimen before the test as a further means of studying the difference in structure of the pieces from the web, flange and root. Microphotographs of pieces KW, KF and KR are shown in Fig. 4. These are magnified sixty-four diameters. The web shows the finest structure, the flange next, while the root is much coarser.

It was noticed that the broken test pieces also indicated this

same difference of structure. If the three pieces, W, F, and R, of any set were placed side by side, W showed a fine surface in the region of the fracture, while F and R were much coarser. The fractured surfaces also indicated the same difference, although to a less extent. An illustration of this difference is shown in Fig. 5, where the magnification is six diameters. The pieces were placed side by side and a photograph taken of the surfaces about one inch from the fracture. This difference was especially noticeable in the beams that were comparatively thick, such as the 15-in. 60-lb. and the 15-in. 80-lb. beams. The fractures for these pieces, even the web pieces, were all coarsely granular. The compara-

TABLE III.—AVERAGE MAXIMUM STRENGTHS OF STEEL FROM WEB, FLANGE AND ROOT.

Beam.	Depth, ins.	Weight, lbs. per ft.	Maximum Strength, lbs. per sq. in.	Remarks.
Standard	6	13.5	65,900	
	10	25	60,600	Beam light for height.
	12	31.5	61,600	" " " "
	12	40	61,600	Beam heavy for height.
	15	42	67,300	Beam light for height.
	15	60	53,700	Beam heavy for height.
	15	80	55,100	" " " "
	18	55	58,100	Beam light for height.
	20	65	64,100	" " " "
Bethlehem	24	73	70,000	Beam light for height.
	18	48.5	57,700	" " " "
	12	36	69,000	" " " "

tively thin beams seemed to show a finer structure. This is indicated in the last column of Table I, the word *silky* always indicating a finer structure.

The small beams showed a fine structure generally, and all the Bethlehem beams tested showed a very fine structure with silky fracture. A comparison of pieces from Beams A (6-in. 13.5-lb.), I (15-in. 80-lb.), and L (24-in. 73-lb. Beth.), is shown in Fig. 6.

The examination of the fractured pieces seems to indicate rather conclusively that the work received by the metal in rolling renders the structure finer, and that this is a probable explanation of the variation in strength. This view is further strengthened by the fact that the elastic limit for the *thin* or *light* beams is uniformly higher than for the *thick* or *heavy* beams. The same

may also be said of the ultimate strength. The yield point is not given, but it was found to differ from the elastic limit much more in the Bethlehem beams than in the standard. The modulus of elasticity was very near 30,000,000 in each case.

An examination of Table III shows that the material for the 15-in. 60-lb. and the 15-in. 80-lb. beams would not pass the specification for the tensile strength. Allowing the liberal margin of 8,000 lbs. per sq. in., as the amount by which the yield point

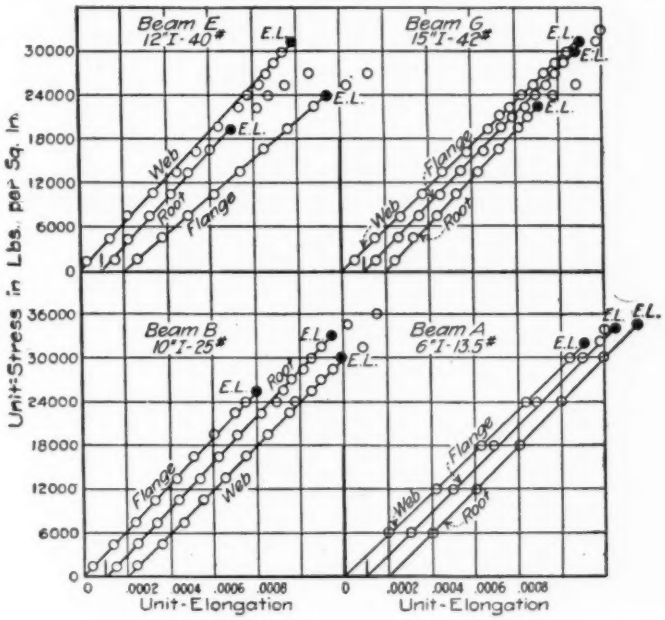


FIG. 3.—Tension Tests of Specimens Cut from Standard I-Beams.

exceeds the elastic limit, two of these pieces would not pass the specification for the yield point.

Since there is a variation of strength in the material cut from different parts of the I-beam, it seems reasonable to suppose that the strength of the material on one side of a test piece is different from that on the other side. That this is true is indicated by the variation in the roughness of the surface of the pieces after test, especially noticeable in pieces cut from the flanges. This is shown in IF, Fig. 6, but is more noticeable in some other pieces not illustrated in this report.

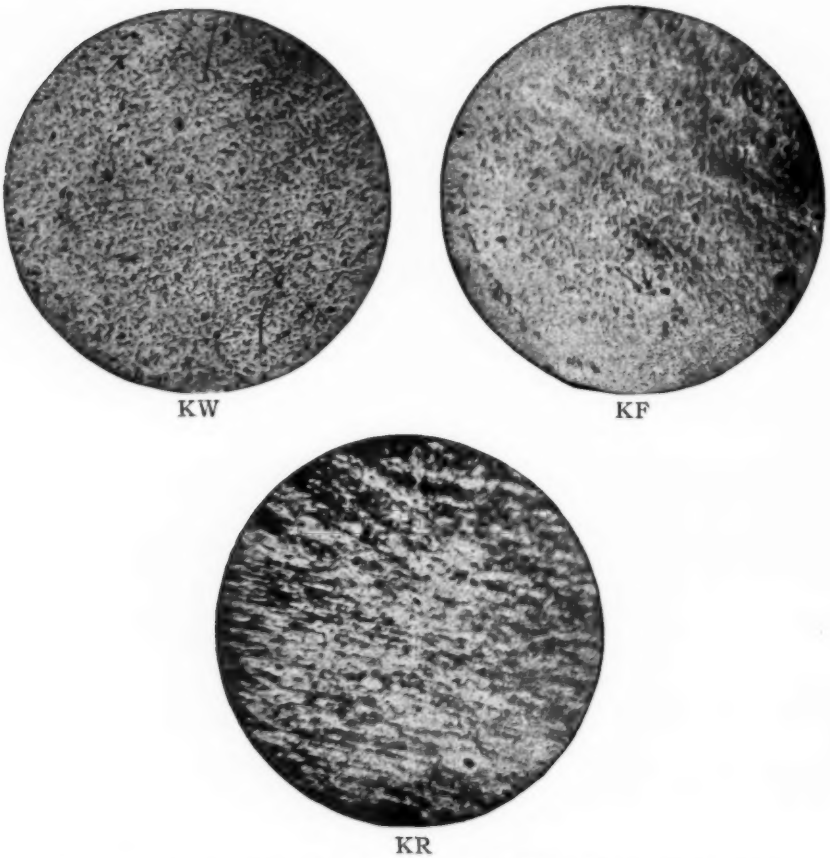
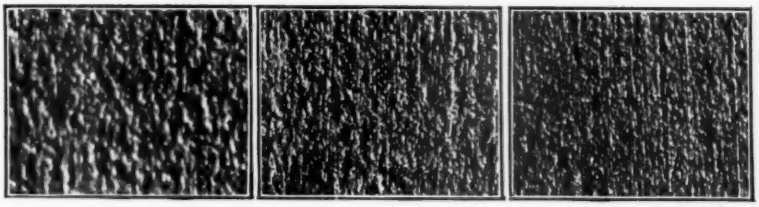


FIG. 4.—Microphotographs of Material from Web, Flange, and Root.
Magnified 64 diameters.
KW and KF are slightly scratched.

To show the variation in the strength of the material in the flange of one beam, L, three pieces were tested, one cut near the root of the web, one from the extreme edge of the flange, and one intermediate. The results are as follows:

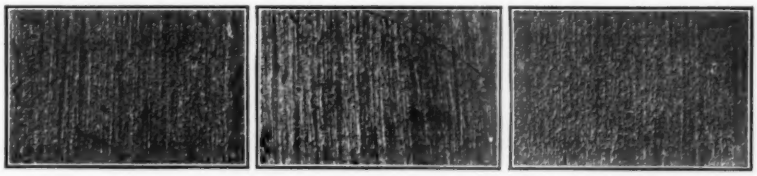
Elastic limit—near root	24,000	lbs.	per sq. in.
Elastic limit—intermediate	34,000	"	" "
Elastic limit—extreme	36,000	"	" "

This again shows the increase of strength with a greater working of the material.

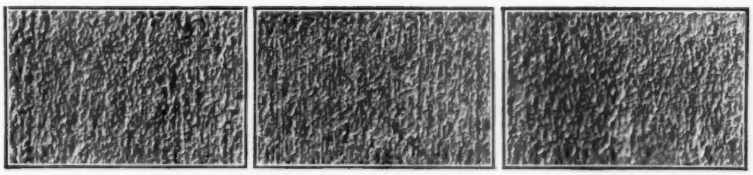


KR KF KW

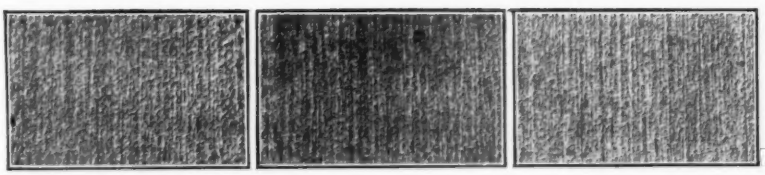
FIG. 5.—Photograph of Fractured Surfaces, Magnified 6 diameters.



AR AW AF



IR IW IF



LR LW LF

FIG. 6.—Comparison of Pieces from Beams A, I, and L.

CONCLUSIONS.

A brief summary of the results may be made as follows:

1. The elastic limit varies considerably for material cut from different portions of the beam, both standard and Bethlehem, being lowest in the root of the web, higher in the flange near the root, and highest in the web. This confirms the work of Professor Marburg.

2. The indications are that there is considerable difference chemically in the material in different parts of the beam. It is desirable that these chemical tests be made and recorded as a part of this investigation.

3. The appearance of the fractured pieces indicates a considerable variation in the density of the material throughout the beam, due probably to the work of rolling. The thin beams (as defined in Table III) show material superior to that of the thick beams.

The writer wishes to thank Mr. George F. Martin and Mr. Frank M. O'Donnell for faithful work in carrying out these tests.

APPENDIX.

Since the presentation of the above paper before the Society, the desired chemical tests have been made through the courtesy of the American Bridge Company of New York. Drillings of the test pieces given below, and numbered consecutively from 1 to 24, were sent to the above company. The results, which are given in Table IV, show a surprising uniformity in the chemical composition of the material in the various beams. This is especially true when it is remembered that the beams were selected at random. The difference in the elastic strength of pieces from the web, flange and root can hardly be attributed to the difference in chemical composition, since such cases as that of Beam J seem to show an increase in strength of the web metal over the flange, in spite of the fact that the web metal is lower in the four chemical constituents. The high values obtained for the elastic limit in pieces from Beam A may be partly accounted for by the high manganese and sulphur, although these pieces are low in carbon. Beam L is higher in carbon than the others, and

this may account in part for the rather high maximum strength of the test pieces from this beam. Nothing in the composition, however, seems to explain why the elastic limit of the web piece

TABLE IV.—STEEL ANALYSIS.

Beam. Mark.	Beam. Depth, ins.	Beam. Weight, lbs. per ft.	Test Piece from	Elastic Limit, lbs. per sq. in.	Carbon, per cent.	Manganese, per cent.	Phosphorus, per cent.	Sulphur, per cent.
A	6	13.5	Web	32,000	0.201	0.558	0.059	0.110
			Flange	34,000	192	610	98	100
			Root	34,000	194	552	94	90
C	10	25	Web	24,750	0.281	0.311	0.112	0.080
			Flange	26,600	288	420	20	31
			Root	27,000	247	458	60	37
H	15	60	Web	19,500	0.238	0.440	0.007	0.028
			Flange	24,000	243	435	06	30
			Root	16,500	248	408	11	27
I	15	80	Web	27,000	0.212	0.435	0.020	0.042
			Flange	19,500	225	422	27	39
			Root	19,500	241	519	26	35
J	18	55	Web	31,500	0.251	0.518	0.021	0.032
			Flange	25,500	268	534	28	37
			Root	19,500	263	481	26	35
K	20	65	Web	34,500	0.238	0.452	0.053	0.024
			Flange	22,500	261	526	66	25
			Root	13,500	253	460	58	27
L	24	73	Web	33,000	0.285	0.389	0.010	0.025
			Flange	24,000	283	436	08	29
			Root	22,500	287	405	07	30
M	18	48.5	Web	19,500	0.232	0.392	0.007	0.049
			Flange	21,000	238	485	10	50
			Root	28,500	232	428	10	48

Beams L and M are Bethlehem Beams; all the others are Standard I-Beams.

for this beam was 33,000, while that for the root was 22,500 lbs. per sq. in.

It seems, then, that these chemical analyses fail to show sufficient reasons for the variation in strength observed in the material from different parts of the beams, and that we must consider the work received by the metal in rolling and the finishing temperatures as the principal factors causing this difference.

DISCUSSION.

The President. THE PRESIDENT.—The difference in properties at different parts of the beam is very instructive. From the first table it appears that among the eleven beams there are eight cases in which the web has a materially higher elastic limit than the flange, and that in only one case does the flange have a much higher elastic limit than the web. Now an explanation of that might perhaps be suggested from the fact that the web would be finished colder than the flange, especially as the test pieces seem to have been cut very near the thick part of the flange, that is, near the root of the section. The material here would, of course, be finished at a considerably higher temperature than at the middle of the web.

Mr. Marburg. MR. EDGAR MARBURG.—I should like to ask Mr. Hancock whether the yield point was observed, and, if so, whether it showed normal or inferior values.

Mr. Hancock. MR. E. L. HANCOCK.—The yield point was not reported. For the standard-beam specimens, the yield point was only a little above the elastic limit, about 3,000 to 4,000 lbs. per sq. in.; and for the Bethlehem beams there was a greater difference between the yield point and the elastic limit, about 8,000 lbs. and, in some cases, 10,000 lbs. per sq. in.

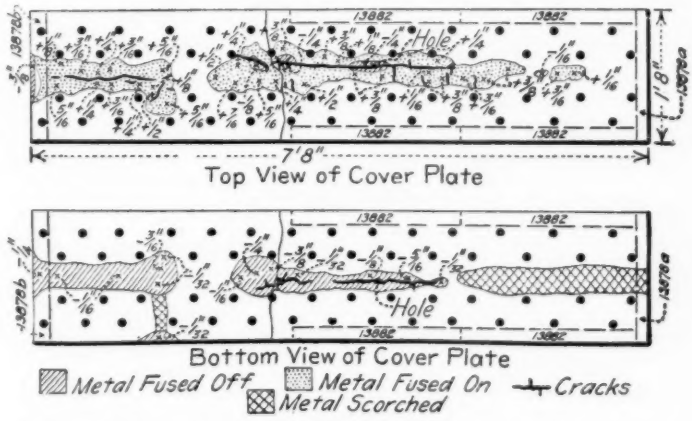
Mr. Marburg. MR. MARBURG.—In the worst case the elastic limit was reported as 13,500 lbs. per sq. in. Does Mr. Hancock remember whether the yield point was very much higher for that particular beam?

Mr. Hancock. MR. HANCOCK.—The yield point, as I remember it, was not very much higher. Its value in that case was about 16,000 lbs. per sq. in.

TEST OF A STRUCTURAL-STEEL PLATE PARTLY FUSED BY A SHORT-CIRCUITED ELECTRIC CURRENT.

By A. W. Carpenter.

The electrification of the N. Y. C. & H. R. R. R. out of the Grand Central Station at New York City, involved carrying electric third rail and electric power cables over the steel Park Avenue Viaduct, about one and one quarter miles long. The cables were placed in steel tube conduits just over the tops of the girders, on which the conduits were supported on wooden blocking.



Note.—Plate ¾-in. thick The fractions denote differences of elevation from normal surface. The locations of test specimens are shown by broken lines and the test numbers; the fracture is shown by the irregular full line across the plate.

Fig. 1.

On June 22, 1907, a short circuit took place which fused the conduit pipe and burned the cover plate of the underlying girder, the burn extending clear through the plate at one point near its center. The conduit metal and cable copper were fused into the plate. The injured portion of the plate was cut off and replaced with a new plate properly spliced to the remaining portion on the

girder, in due course of repairs. It was thought desirable to determine the extent of the injury to the strength characteristics of the plate due to any possible change in the character of the material; that is, any injury aside from the mere loss of section. The removed portion was therefore sent to the Watertown Arsenal for tensile tests, and microscopic examinations of the structure of various parts were made.

The removed piece of the cover plate is shown in Fig. 1* and in the photograph Fig. 2 which shows the top side.

The specifications for the material of the viaduct call for

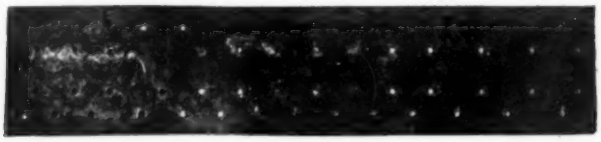


FIG. 2.—Photograph of Top Side of Cover Plate.

open-hearth steel made from raw material "within the Bessemer limits of phosphorus 0.10 per cent. and sulphur 0.05 per cent." The specified properties were as follows:

Chemical Composition.

Phosphorus	not over	0.08 per cent.
Sulphur	" "	0.06 " "
Manganese	" "	0.40 " "

Specimen Tests (Structural Steel).

Tensile strength—58,000 to 65,000 lbs. per sq. in.
Elastic limit—not less than 38,000 lbs. per sq. in.
Elongation in 8 ins. for plates less than 36 ins. wide—not less than 28 per cent.
Quench bend test from low cherry red, flat without visible cracks.

The original mill test report on the material of this particular plate could not be identified, but test reports on material for the same portion of the viaduct are at hand. One, covering plates, shows that the material was acid open-hearth steel manufactured by the Carbon Steel Company, and tests on a specimen from a 2.4 by $\frac{15}{16}$-in. plate gave the following results:

*Acknowledgment is made to the *Engineering Record* for the use of the drawing from which the cut for Fig. 1 was prepared.—ED.

Chemical Composition.

Carbon	0.13	per cent.
Manganese	0.36	" "
Phosphorus	0.075	" "
Sulphur	0.016	" "

Physical Properties.

Elastic limit	39,780 lbs. per sq. in.
Ultimate strength	59,120 " " " "
Elongation in 8 ins.	29.5 per cent..
Reduction of area	60.8 " "
Fracture	silky.
Cold bend	180° flat.

The tests of the injured plate were conducted under the direction of Dr. P. H. Dudley.

At the Watertown Arsenal the 800,000-lb. testing machine was employed with the following results:

WATERTOWN TEST NO. 13877.

(See Figs. 1, 2, 3, 4 and 5.)

On plate 20.12 ins. wide by 86.75 ins. long by 0.77 in. average thickness, shown in Figs. 1 and 2. Original gross sectional area, 15.49 sq. ins. Area of unburned metal, measured on fractured section, net, 12.3 sq. ins. Gage lengths of 60 ins. (laid off every inch) laid off 1½ ins. from east and west edges of plate.

Applied Loads.		Elongation in 60 ins.		Remarks.
Total, lbs.	Lbs. per sq. in. on Net Section, 12.3 sq. ins.	East Edge, in.	West Edge, in.	
15,490	1,260	0	0	
77,450	6,300	0.01	0.01	
154,900	12,600	0.02	0.02	
232,350	18,800	0.04	0.03	
309,800	25,200	0.05	0.04	
325,290	26,400	0.06	0.04	
340,780	27,700	0.06	0.05	Snapping sounds.
356,270	29,000	0.06	0.06	" "
371,760	30,200	0.07	0.06	
387,250	31,500	0.07	0.07	
402,740	32,700	0.08	0.08	
418,230	34,000*			

* Tensile strength.

Dimensions at fracture: 20.12 by 0.76 ins. (maximum thickness); irregular section.

Appearance of fracture: finely granular, 75 per cent.; dark brown and blue black, 25 per cent.

WATERTOWN TEST NO. 13878.

Specimen *a*. (See Figs. 1, 6 and 7.)

Transverse strips, one from each end of plate, 1.79 ins. wide by 20.12 ins. long by 0.77 in. thick.

Elastic limit: total, 55,100 lbs.; per square inch, 39,927 lbs.
Tensile strength: total, 79,700 lbs.; per square inch, 57,753 lbs.
Sectional area: 1.38 sq. ins.
Elongation in 10 ins.: 1.06 ins. (=10.6 per cent.).
Area at fracture: 0.64 by 1.67 ins. (=1.07 sq. ins.).
Contraction: 22.4 per cent.
Elongation of inch sections: 0.09, 0.08, 0.07, 0.08, 0.21*, 0.13, 0.11, 0.09, 0.09, 0.11.
Appearance of fracture: silky, with brown streak through center.

Specimen *b*. (See Figs. 1, 6 and 7.)

(This specimen was burnt across middle by the electric current.)

Elastic limit: total, 32,600 lbs.; per square inch, 37,172 lbs.
Tensile strength: total, 33,150 lbs.; per square inch, 37,800 lbs.
Sectional area: 0.877 sq. in.
Elongation in 10 ins.: 0.07 in. (=0.7 per cent.).
Area at fracture: 0.39 to 0.64 by 1.63 ins. (=0.838 sq. in.).
Contraction: 4.4 per cent.
Elongation of inch sections: 0, 0, 0, 0, 0.05, 0.02, 0, 0, 0, 0.
Appearance of fracture: coarse granular.

WATERTOWN TEST NO. 13882.†

(See Fig. 1.)

Longitudinal strips, two from each edge of plate, cut off and tested after the test was made of the full-width plate; 1.91 ins. wide by 24.85 ins. long by 0.76 in. thick.

Elastic limit: total, 51,300 lbs.; per square inch, 35,379 lbs.
Tensile strength: total, 80,500 lbs.; per square inch, 55,534 lbs.
Sectional area: 1.45 sq. ins.
Elongation in 10 ins.: 2.72 ins. (=27.2 per cent.).
Area at fracture: 0.45 by 1.30 ins. (=0.585 sq. in.).
Contraction: 59.6 per cent.
Elongation of inch sections: 0.21, 0.19, 0.19, 0.16, 0.17, 0.19, 0.21, 0.22, 0.28, 0.88.*
Appearance of fracture: silky.

* Indicates elongation in the inch section in which the fracture occurred.

† The results here given are the averages of those obtained on the four specimens, which tested quite uniformly.

FIG. 3.—Test No. 13877: Fractured Ends.

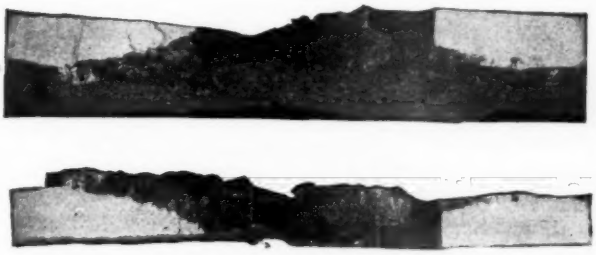


FIG. 4.—Test No. 13877: Central Portion of Fractured Ends.

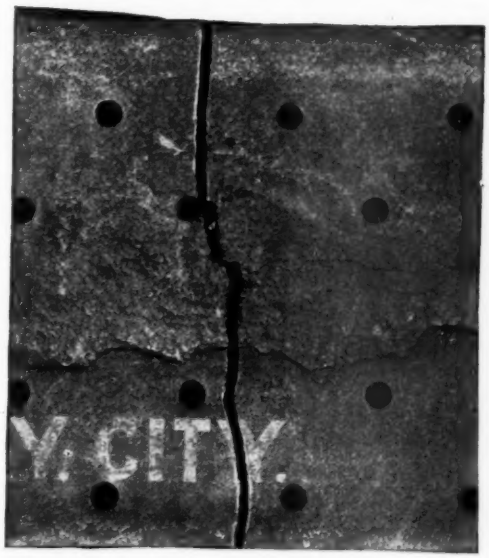
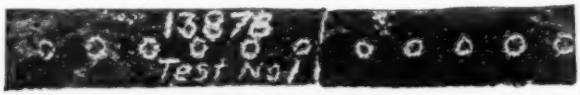


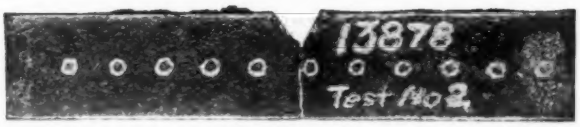
FIG. 5.—Test No. 13877: Fracture of Plate.
(Note that the full width of the plate is not shown.)

The Watertown tests are certified to by Messrs. J. E. Howard and C. B. Wheeler.

Photographs of the various test specimens are shown in Figs. 3, 4, 5, 6 and 7.



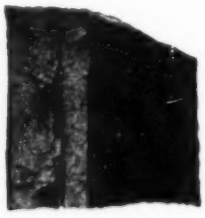
Specimen *a*



Specimen *b*.

FIG. 6.—Test No. 13878.

Microscopic studies by Dr. Dudley of parts of the plate cut from fused and from unaffected portions revealed the following conditions: The parts unaffected by the fusing showed a fine structure without distinct granulations and with the excess of



Specimen *a*.

Specimen *b*.

FIG. 7.—Test No. 13878: Fractured Ends.

ferrite common to low-carbon bridge steels. The structure of the fused portions was changed and enlarged, from which it was concluded that the material would be rendered brittle (which was borne out by the subsequent tensile tests). The welding of the copper and steel from the conductor and conduit with the steel of the plate was complete and did not show distinct enclosures

of any oxides between the surfaces. The general structure of the plate showed a number of original enclosures of oxides such as are commonly found in all plates. It was considered that the original material should be classed as excellent.

The conclusion drawn from the tests was that the character of the metal was changed by the electric burning, but that the injury did not extend far beyond the limits of the visible burning. This local change in the character of the metal was enough,

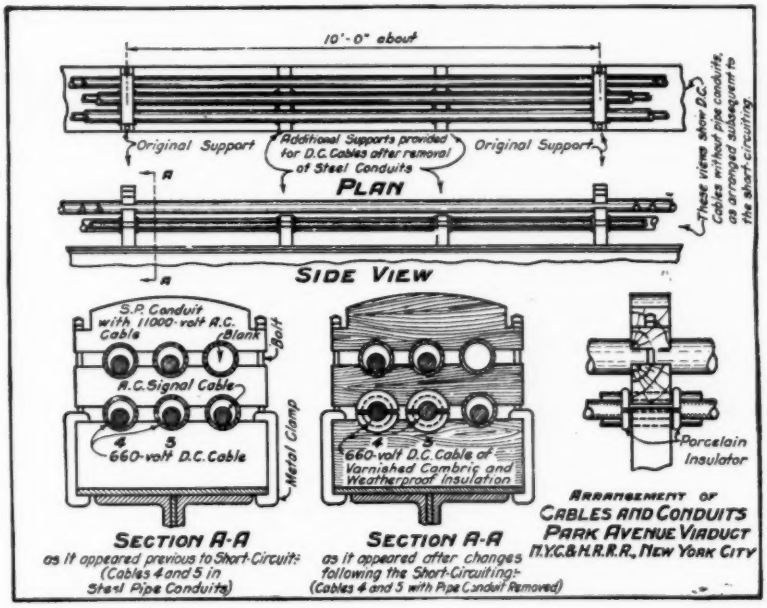

10'-0" about
Original Support
Additional Supports provided for D.C. Cables after removal of Steel Conduits
Original Support
PLAN
SIDE VIEW
These views show D.C. cables without pipe conduits, as arranged subsequent to the short-circuiting
S.P. Conduit with 11000-volt A.C. Cable
Blank
Bolt
A.C. Signal Cable
4
5
660-volt D.C. Cable
Metal Clamp
660-volt D.C. Cable of Varnished Cambric and Weatherproof Insulation
Porcelain Insulator
SECTION A-A
as it appeared previous to Short-Circuit: (Cables 4 and 5 in Steel Pipe Conduits)
SECTION A-A
as it appeared after changes following the Short-Circuiting: (Cables 4 and 5 with Pipe Conduit Removed)
ARRANGEMENT OF CABLES AND CONDUITS PARK AVENUE VIADUCT N.Y.C.&H.R.R.R., NEW YORK CITY

FIG. 8.

however, to reduce the static strength of the plate tested as a whole some 40 per cent. and to destroy its ductility; from which it was further concluded:

1. That a plate with a similar injury would be unreliable for service; and

2. That if the local injury were cut away the balance of the section could be depended upon to develop practically the same unit strength as prior to the injury.

The damage to the plate is considered due to the heat pro-

duced, in which electricity was merely the producing agent, and it is thought that a similar amount of heat produced in any other way and applied to the same parts for the same period of time would have given the same results.

It may be of interest to state that the short circuit which caused the injury developed between the 660-volt direct-current conductor and the steel conduit, and was probably due to a defect in the insulating wrapping at a joint in the cable. The damage would probably have been confined to the cable and conduit had it not been for the failure of an operator to perform his duty in opening a circuit breaker; as a result of this failure, the current was continued for a considerable period of time.

After the accident a means was found by which the heavy current cables were removed from the greater length of the viaduct; and over the remainder the steel conduits were removed from these cables and replaced with a non-conducting covering. This arrangement has proven entirely satisfactory and there has been no later instance of a short circuit from the cables. The arrangement of the cables and conduits is shown in Fig. 8.

CUPRO-NICKEL STEEL.

By G. H. Clamer.

A systematic study of the properties and constitution of a complete series of alloys presents a most interesting field of research. It has only been within the past comparatively few years that methods have been devised for the proper study of the constitution of alloys, by means of which a better understanding of their properties is to be gained. Practically all the binary alloys have been studied up to the present time,—at least of all the more important metals,—but the constitution of the ternary and quaternary combinations presents an almost endless field for research. The study of the combination of metals to form alloys is particularly interesting because the results obtained are often most surprising and least expected, and even with our present knowledge are unexplainable and quite the reverse of what might be predicted. A few examples of the surprising results due to the combination of metals to form alloys are as follows:

1. The magnetic properties of certain alloys of manganese with aluminum, two metals having no magnetic properties.

2. The extremely high melting point of certain alloys of antimony and aluminum, two metals of comparatively low melting point.

3. The disintegration of certain alloys of iron and aluminum, nickel and aluminum, and manganese and aluminum, which disintegrate after some months' standing and actually fall to powder.

4. The surprising ductility of certain ternary alloys, which result from the addition of two metals to a third, in such proportions, that were either of them added separately in the proportions in which they exist in the ternary alloy, they would make an alloy which is quite brittle. The alloy particularly referred to was discovered by Sir Robert A. Hadfield, and

described by him in the Proceedings of the Iron and Steel Institute, 1905. It is of the following composition:

Carbon	0.6	per cent.
Manganese	5.04	" "
Nickel	14.55	" "

This steel has an ultimate strength of 60 tons per sq. in. and an elongation of 70 per cent.

One of the series of alloys which I am about to describe in this paper is an alloy of this nature. It has copper present in such proportion, that were it alone added to the steel, it would render it exceedingly brittle,—i. e., such a steel would have practically no elongation whatever,—whereas with the joint addition of nickel there results an alloy of high ductility. Before describing this alloy, it would probably be well to review the results of various investigators who have studied the binary alloys of iron and nickel, and iron and copper, both with and without carbon. The iron-nickel alloys may apparently be divided into three classes, viz.:

1. Those containing less than 8 per cent. of nickel, which have a pearlitic structure.

2. Those containing from 8 to approximately 25 per cent. of nickel, which have a martinsitic structure.

3. Those containing above 25 per cent. of nickel, which have a crystalline structure.

These proportions, however, are not absolutely fixed, but are dependent to a great extent upon the carbon content, transitions taking place at lower percentages of nickel with higher percentages of carbon.

Messrs. Charles Burgess and James Aston, of the University of Wisconsin, recently investigated the complete series of nickel alloys with electrolytic iron of high purity, so that the effect of the alloying metal was due to nickel alone, and not to some combined influence which might result from the use of more impure material. They confirmed the existence of these three ranges in the constitution of nickel-iron alloys. The effect of the nickel on the iron, as they describe it, is as follows:

1. In the range of lower nickel content, it increases the strength with a slight decrease of ductility.

2. Beyond this range, the addition of nickel causes a sudden increase of strength with a marked decrease of ductility over a zone of decided brittleness.

3. The position of the brittle zone varies with the carbon content and probably with a variation in the other impurities, such as manganese, if present in appreciable amounts. For a pure alloy, where the effect is due to nickel alone, the zone may be set between 10 and 16 per cent. of nickel. The addition of carbon places the zone at lower percentages of nickel, beginning in the neighborhood of 10 per cent. for a carbon content of 0.22 per cent. and at about 7 per cent. of nickel for a carbon content of 0.82 per cent., where the other impurities are small. It may commence as low as 5 per cent. of nickel in medium-carbon steels (C. = 0.44 per cent.) where the manganese rises to 1 per cent. Accompanying this brittleness, there is a marked hardening in the material.

4. Annealing, while not greatly affecting the region of the brittle zone or the extent of the brittleness, has a tendency to confine the range to more narrow limits.

5. For percentages of nickel above those of the zone of brittleness, there is a restoration of the ductility and softness.

The iron-copper alloys have also been investigated quite thoroughly by a number of investigators, but with very conflicting results, which were no doubt due to the influence of carbon in the alloys under investigation. It was formerly thought that iron and copper would not alloy, except in very small proportions of one with the other, but it has now been thoroughly demonstrated that the extent to which copper will alloy with iron is dependent entirely upon the carbon content. Carbonless iron and pure copper will mix in all proportions, and will not separate into two conjugate layers in the cast ingot. Stead has shown that the complete series of copper-iron alloys, according to their constitution, may be classed into three distinct series, viz.:

1. Alloys containing a trace of iron, to those containing 2.73 per cent. of iron and 97.2 per cent. of copper.

2. Alloys containing between 2.73 per cent. of iron and 97.2 per cent. of copper, and 92 per cent. of iron and 8 per cent. of copper.

3. Alloys containing between 8 per cent. and a trace of copper.

The first class is quite homogeneous, consisting of but one structural constituent. The second class consists of two structural constituents. The third class also has but one

structural constituent, which, however, is made up of crystals which are richer in copper in the last portion to solidify.

The properties of these copper-iron alloys have also been recently investigated by Messrs. Burgess and Aston, and they have found that additions of copper up to 8 per cent. cause an increase in ultimate strength and a diminution in ductility, and that alloys with 8 per cent. have no ductility whatever. As a result of this valuable research, they have recommended for commercial use the alloy with 1.5 per cent. of copper, this alloy having very much the same properties as nickel steel with 3.5 per cent. of nickel. Still, it must be remembered that this alloy was made from practically carbonless iron, and, therefore, would no doubt present some practical difficulties in its manufacture.

I have reviewed these iron-nickel and iron-copper series of alloys, in order to show, as I have stated before, what surprising results are obtained by the joint addition of copper and nickel. For example, alloys can be produced carrying from 5 to 20 per cent. of copper, which without nickel would be extremely hard, brittle and red short, but which, by the addition of nickel in the proportion of from 20 to 50 per cent., become highly ductile, easily forgeable, and easily machinable. Such alloys are capable of being rolled into sheets or rods, and can be machined without difficulty —in fact, they are quite soft.

The following are tests of two typical alloys within these ranges of proportions:

	No. 1.	No. 2.
Copper, per cent.	9.00	19.50
Nickel, per cent.	22.00	45.00
Carbon, per cent.	0.22	0.20
Ultimate strength, lbs. per sq. in	101,000	98,230
Elastic limit, lbs. per sq. in.	57,300	54,150
Elongation, per cent.	42.5	35.0
Reduction of area, per cent.	61.5	47.9

These tests were made on rolled rods. The elastic limit, it will be noted, is quite low in proportion to the ultimate strength, which naturally accounts for the softness. Alloys at the lower end of the series can be bent cold to an angle of 180° without fracture, whereas those at the higher end cannot be bent so far. Alloys at the lower end of the series will resist corrosion in a highly

satisfactory manner, and those at the upper end are practically non-rusting. Samples which have been exposed for the past year in contact with concentrated foundry gases, and at Atlantic City in contact with salt atmosphere, have demonstrated these facts. In addition to this, the alloys have a very low coefficient of expansion.

Just what uses such alloys might be put to has not yet been determined, but no doubt quite a number will suggest themselves: e. g., as a substitute for the present 25- to 35-per cent. nickel steels, and probably for quite a number of others. For the cupro-nickel steel can be produced at a very much lower cost, not only because of the substitution of copper for nickel (copper selling at the present time at less than one-third the price of nickel), but because the alloy can be made from monel metal, a commercial alloy of copper and nickel, containing copper and nickel in the correct proportions for making such a steel. Monel metal sells for about the price of copper. It is also possible to make the steel directly from Sudbury nickel ores, by simply smelting and Bessemerizing them to eliminate the iron to the extent desired, roasting the matte produced, and finally reducing the combined oxides resulting from roasting the matte. It is thought that either by the use of monel metal for making the steel alloy, or by the direct production of it from the ore, the cost of production might be sufficiently reduced to make it attractive for roofing, gutters, spouts, ventilators, and for many other uses where its resistance to corrosion and its low coefficient of expansion will warrant the cost. Sheets of cupro-nickel steel can be produced to sell at a very much lower price than copper sheets, and probably for two to four times the price of commercial coated iron and steel sheets; but since the alloy is about twice as strong as the soft steel and three times as strong as copper sheets, thinner gauges can be used. The alloys at the higher end of the series, as I have said before, are non-rusting.

Steels within this range of proportions of copper and nickel have a crystalline structure, such as is possessed by nickel steels carrying above approximately 25 per cent. of nickel, or with a somewhat lower percentage of nickel if carbon is present in an appreciable amount,—in other words, like nickel steel within the crystalline range,—the copper apparently acting very much like

nickel. It will be noted that the physical properties are very similar to those of the same nickel steels without copper.

Noting the curious and unexpected results obtained with these high copper-nickel alloys, I became curious to know what would be the effect of replacing part of the nickel in nickel steel within the pearlitic range by copper, and accordingly made such steels with from 1 to 8 per cent. of monel metal, in which the proportion of nickel to copper is roughly 2.5 per cent. of nickel to 1 per cent. of copper. Here again the copper really acts like so much nickel, at least when present in these relative proportions, and it is possible, therefore, to produce a steel of practically the same physical properties as nickel steel, at very much reduced cost. In these steels the nickel, iron, and copper are in the same relative proportions in which they occur in some of the prominent mines at Sudbury, where vast deposits exist. The average analysis of these ores is as follows:

Copper	0.8	to	2.00	per cent.
Nickel	2	to	5.00	" "
Iron	35	to	52.00	" "
Sulphur, Gangue	Remainder.			

It will be seen that, by the operation of reducing this ore to matte, calcining the metal to remove the sulphur, and reducing the calcined product, this steel can be produced to almost any desired formula. The valuable properties of the nickel steels—i. e., steels carrying below 6 per cent. of nickel—have of course long been recognized, and recently the value of copper as a valuable constituent of steel, instead of a metal to be looked upon as a detrimental impurity, has also become recognized. It is probably not quite so surprising, therefore, that the joint addition of copper and nickel within the range of proportions here considered is productive of valuable results. The addition of these two metals in combination seems to have the same effect upon the steel as if they were individually added, the copper in its effect really being about the same as so much added nickel. It is possible, therefore, to replace part of the nickel in nickel steel by copper, without materially altering its physical properties. The following table gives the physical properties of some of these alloys:

No.	Monel Metal, per cent.	Carbon, per cent.	Ultimate Strength, lbs. per sq. in.	Elastic Limit, lbs. per sq. in.	Elongation, per cent.	Reduction of Area, per cent.
1	4	0.11	83,600	66,300	26.5	65.4
2	3	0.10	75,300	64,600	25.5	71.4
3	2	0.15	75,500	63,700	28.0	65.4
4	4	0.61	151,000	120,000	8.0	15.8

Recently Messrs. Burgess and Aston, working quite independently of me, have confirmed these results with alloys which they have made with electrolytic iron, which has been quite gratifying.

Although I have not had an opportunity to study all the properties of some of the alloys within these ranges, i. e., the pearlitic and crystalline alloys, nevertheless, it would seem from the tests so far made, that these alloys may become of commercial value, especially as we now have at hand a comparatively cheap material from which they can be produced,—monel metal,—and the further possibility of producing them directly from Sudbury ores.

DISCUSSION.

Mr. Mathews.

MR. JOHN A. MATHEWS.—In looking over the list of papers to be presented this year to the Society, I noticed the paper by Mr. Clamer on "Cupro-Nickel Steels." The title does not in any way define the scope of the paper, but it brought to my mind two thoughts; first, the general subject of copper in steels, and second, some experiments that we made a year or two ago in connection with a nickel steel containing an unusually great amount of copper. In looking up this subject, I was surprised to find how little attention has been given, in papers and discussions that have been presented to the Society during the past five or six years, to the general subject of copper in steel. So far as I recall, none of the specifications of the Society mention copper at all; however, I find that there is still a prejudice against copper in the minds of many users of steel.

A year or two ago, we sent a large quantity of spring steel to the Panama Canal. Upon its receipt, we were advised that the copper content was from 0.07 to 0.12 per cent., whereas the specification had stated that the steel was subject to rejection if the copper exceeded 0.05 per cent. Our own analyses confirmed the fact that the content of copper in the steel was higher than we had expected, but the writer looked up the authorities on the subject and presented such an eloquent and convincing brief, that not only was the steel accepted, but specifications since that time have omitted any reference to the copper content.

In connection with nickel steel, a firm of automobile manufacturers formerly specified that the copper in their nickel steel should not exceed 0.025 per cent. The writer was instrumental in getting this specification changed so that the user shifted the decimal point one place to the right, making the permissible amount 0.25 per cent., and still later omitted all mention of copper in his specification.

It is hardly necessary here to review the large number of recent investigations that have been made in connection with this subject; as, for example, the articles that have appeared in the

Mr. Mathews.

Proceedings of the Iron and Steel Institute of late years by Stead, Wigham, Colby, Breuil, and others; also, articles by Dillner, Müller, and Bischoff, in *Stahl und Eisen*, together with the statements by Harbord, Campbell, and Howe, in their general treatises on steel. It is, perhaps, a surprise to many to know how generally present copper is in all kinds of steel, even in the best grades of Swedish materials. Bischoff, to whom we have just referred, published the analyses of some forty or fifty samples of German and Swedish steels, and every one of them contained copper in amounts varying from mere traces up to 0.274 per cent. It is sufficient to say, however, that the general trend of scientific work in connection with the influence of copper on steel has been to show that, in any ordinary quantities in which it is likely to be found, its effect is not marked one way or the other, or may even be beneficial.

The particular experiment in reference to cupro-nickel steel to which I should like to refer is of perhaps more than ordinary interest, owing to the fact that the heat of nickel steel containing copper was melted in our Héroult electric furnace, and that the pig iron used in this heat was produced in Canada in the Héroult smelting furnaces which were installed there some years ago; that is, the entire heating from the ore to the finished product was by means of electricity. This is probably the first heat of steel so made in the United States. The pig iron, as produced from certain of the Canadian ores, carries a considerable amount of nickel and copper, and it was with a view to seeing what results could be obtained from this pig iron that we made a cold heat, charging cold pig and ore into our furnace. This heat gave steel of the following analysis:

Carbon	0.44	per cent.
Silicon	0.034	" "
Manganese	0.50	" "
Phosphorus	0.013	" "
Sulphur	0.013	" "
Nickel	3.62	" "
Copper	0.48	" "

It must be remembered that all the nickel and copper present were contained in the original pig iron used. We had no definite analysis in mind when we started this heat, but were more inter-

Mr. Mathews. ested in finding what grade of steel would result from the grade of pig used. The ingots were clean and worked very satisfactorily under the hammer, and the 0.48 per cent. of copper present seems to have exerted no deleterious influence as regards the heating or working.

For the sake of comparing this steel with another steel of approximately the same analysis, we selected an open-hearth nickel steel which analyzed as follows:

Carbon	0.46	per cent.
Silicon	0.066	" "
Manganese	0.70	" "
Phosphorus	0.021	" "
Sulphur	0.034	" "
Nickel	3.36	" "

An examination of this heat showed that it also contained about 0.10 per cent. of copper.

The physical tests to be mentioned later were made from round bars, $\frac{7}{8}$ in. in diameter, and the greatest care was used in their heat treatment. Tests were made in duplicate, and the annealing of the bars from the two heats was done at the same time, so as to avoid any possible difference in the annealing temperature. It was noted that the open-hearth steel machined a little more freely than the electric-furnace steel containing 0.48 per cent. of copper, but here the superiority ended. The tensile tests of the material as rolled gave the following values:

	O. H. Nickel.	Cupro-Nickel.
Elastic limit, lbs. per sq. in.	74,625	72,400
Tensile strength, lbs. per sq. in.	122,000	115,000
Elongation in 2 ins., per cent.	16	22
Reduction in area, per cent.	34	51

In the annealed condition the physical tests were as follows:

	O. H. Nickel.	Cupro-Nickel.
Elastic limit, lbs. per sq. in.	64,750	63,750
Tensile strength, lbs. per sq. in.	119,000	107,300
Elongation in 2 ins., per cent.	17	25
Reduction in area, per cent	37.5	48

Samples of both steels were heated to 1,500° F., quenched in oil, and drawn back to a temperature of 800° F. and maintained

at that temperature for twenty minutes. In this condition, the results of physical tests were as follows: Mr. Mathews.

	O. H. Nickel.	Cupro-Nickel.
Elastic limit, lbs. per sq. in.	154,500	154,000
Tensile strength, lbs. per sq. in.	175,000	172,500
Elongation in 2 ins., per cent.	9.75	13.25
Reduction in area, per cent.	30.8	49.1

In all of the above tests, the elastic limits and tensile strengths are not very different for the two steels, but the great superiority of the cupro-nickel steel in elongation and reduction of area is most noticeable. The presence of the copper certainly has not in any way decreased the toughness of the steel, as manifested in its percentage of elongation and reduction of area, but the most remarkable difference in the two steels was noticed in samples which had been quenched as before at 1,500° F. and drawn back to 600° F. In this condition, both steels showed an elastic limit of about 185,000 lbs. per sq. in., and a tensile strength slightly above 200,000 lbs. per sq. in.; but, while the open-hearth steel was decidedly brittle after this treatment, giving only 2 per cent. elongation and 4 per cent. reduction in area, the electric-furnace product gave 12 per cent. elongation and 46 per cent. reduction in area.

So far as this single test is concerned, therefore, there is absolutely no evidence to show that the copper has exerted a harmful influence upon the nickel steel, and we must either ascribe its superiority to the presence of copper, or to the superiority of the electric method of melting, or to both acting jointly. From an extended experience with the electric-furnace product as compared with the open-hearth nickel steels in carbons varying from 0.10 up to 0.50 per cent., there no longer remains any doubt in my mind as to the superiority of the former over the latter.

The Héroult furnace with which I have had experience was the first commercial electric furnace installed in the United States, and the result of this experiment, where both the pig iron and the steel were of electric furnace origin, seemed to me of sufficient interest to present to the Society.

MR. JAMES A. AUPPERLE.—I should like to know what the effect of high nickel-copper content would be upon the carbon. Ordinarily, when 25 per cent. of nickel is added to steel, it is Mr. Aupperle.

Mr. Aupperle. impossible to introduce enough carbon to make the steel harden, and we cannot give it the temper on account of the carbon being thrown into the graphite condition. I should like to know if the copper modifies this effect in any way.

Mr. Clamer. MR. G. H. CLAMER.—It does not seem to.

Mr. Hunt. MR. ROBERT W. HUNT.—The fact that copper has been ignored in specifications may be accounted for by the experience that the early steel makers had with the use of Cornwall irons. I know in the old days I made any quantity of rails that contained 0.5 per cent. of copper, and with all due modesty I should say they were pretty good rails. I wish I could get something like them to-day. Of course, the sections were smaller and designed for lighter traffic; but the Pennsylvania Steel Company, as well as the Bethlehem and the Troy works, used that Cornwall iron containing low phosphorus and high copper—and incidentally a little high sulphur too—as their basis for a long time. Those experiences largely account, I think, for the fact that copper has been ignored in most specifications. Certainly this paper and the contributions we have had are very interesting. It must be largely along the lines of alloys that we are to look for the principal advancement, or at least one interesting line of advancement, particularly when we realize the very large ore deposit which has lately been opened in northern Cuba, containing at least two of the elements—what may be called the rare elements—which will be in the pig iron made from that ore.

Mr. Reynders. MR. J. V. W. REYNDERS.—The thought occurs to me that we have a natural combination of elements in the Cuban mines to which Mr. Hunt has referred. In the case of the Cornwall mines, as you probably know, we have in recent years eliminated copper from a portion of the ore in order to recover the value of the copper. I am quite sure that so far as a great many uses are concerned, copper has been beneficial. We think, for instance, that in rails it has had a helpful effect. We expect presently to have some information as to the mixture of the Cuban iron containing nickel and chromium with Cornwall iron containing copper, and a little later we may have something of interest to say on that subject.

Mr. Souther. MR. HENRY SOUTHER.—The information before us right now is that copper is beneficial, and especially as affecting the

quality of the steel as tested. My experience has indicated that copper is a detriment to welding, particularly in welded tubes. It seems to have an effect on the welding very much worse than that of sulphur. Steel which is inferior as to sulphur and phosphorus—in fact, what would have been called in the old days a high-phosphorus and high-sulphur steel—welds better than steel distinctly purer as to phosphorus and sulphur but containing between 0.25 and 0.50 per cent. of copper. The tube skelp does not weld soundly, but proves red-short and troublesome. If there is any information along that line showing different results, I think we ought to have it on our records. **Mr. Souther.**

MR. AUPPERLE.—I have had a little experience with the welding of steel containing 1 per cent. of carbon and about 0.50 per cent. of copper. The welding was done with an electric welder. It proved very satisfactory, and the material when made into saws gave very good service. **Mr. Aupperle.**

MR. H. J. FORCE.—Our chief engineer sent me an 80-lb. rail a few weeks ago which was made by the Lackawanna Steel Company about fifteen years ago. He wanted to know if we could tell him why it was such a good rail. An analysis showed about 0.40 per cent. carbon and about 0.60 per cent. copper. Those rails have given very good service. We have quite a number of the Lackawanna Iron and Steel Company's rails on branch lines. **Mr. Force.**

COPPER-CLAD STEEL: ITS METALLURGY, PROPERTIES AND USES.

By Wirt Tassin.

For many years attempts have been made to cover steel with a copper coat which could be made of any desired thickness, and to so unite the two metals that the combined product could be submitted to any of the usual methods for working metals without destroying the integrity of this union. The methods tried in the past have been more or less successful failures, both from a metallurgical and a commercial standpoint, and it is only recently that a process has been developed by the Duplex Metals Company, of Chester, Pa., for the successful welding of copper to steel so that it will withstand the many methods used for working metals and be at the same time a commercial product.

The weld between the copper and the steel (Fig. 1) is perfect, within the limits of a metallurgical process. The two metals are united in such a manner that the copper can be separated from the steel only by melting it off. The weld will resist sudden and severe temperature changes, such as heating the metal red hot and quenching it in ice-cold water. It will resist stress or shock, as shown in Fig. 2, which is a section of a 7-in. round that has had the copper cut through to the steel, the section placed in a vise and then repeatedly struck with a hammer. The clad metal can be rolled, swaged, or drawn, hot worked or cold worked, and the proportion of copper and steel existing in the original billet will remain nearly a constant no matter what the reduction may be, as, for example, from a 6-in. billet to a No. 12 wire.

The process by which copper-clad steel is made may be described as follows: Steel billets of any desired composition—which, for the purposes of this description, will be regarded as being suitable for making telephone wire—is rolled to a $5\frac{1}{16}$-in. round. The bar is then cut into 26-in. lengths. The billets then pass into a machine where both ends are drilled and tapped. From here they go into a special pickle. After pickling and

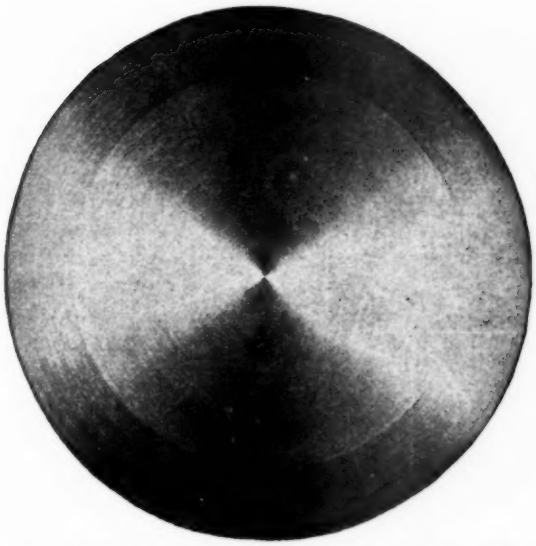


FIG. 1.—Section of a Copper-clad Steel Billet. Full size.

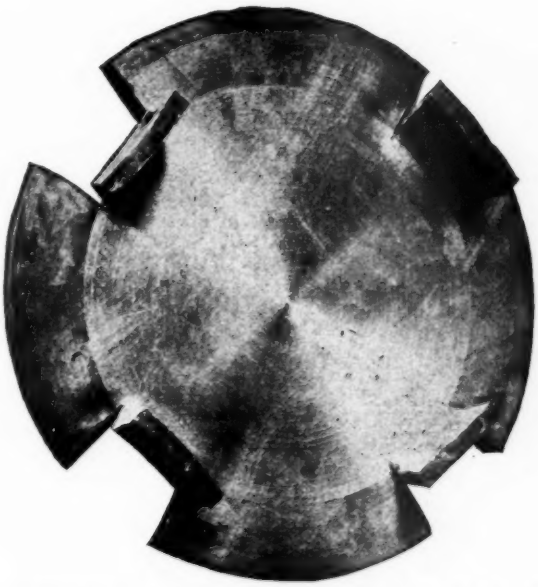


FIG. 2.—Copper-clad Steel, Hammered to show Weld. Full size.

washing, the billet is placed in a pre-heater and is brought up to a given heat. When the desired temperature has been reached, the billet is drawn up into a tube (also previously heated) by means of a rod and a bushing screwed into the billet. This rod slides up and down in the center hole of a three-jaw chuck which holds the tube and centers the billet in it. A steel flange is then screwed on the bottom of the billet, forming with the tube a mold the core of which is the billet. The mold and billet is now carried to a furnace of special design, which contains a specially prepared copper. The billet with its attached flange is then lowered out of the tube

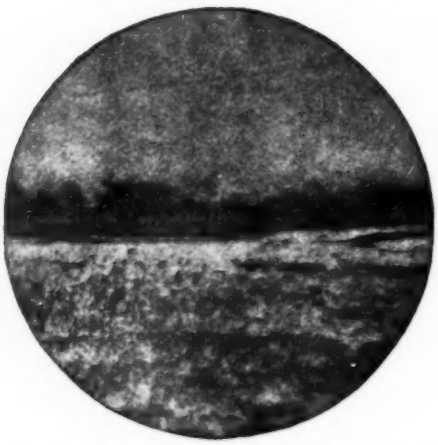


FIG. 3.—Longitudinal Section showing Weld Area in a ⅜-in. Copper-clad Rod. (× 125.)

and into this copper, and kept there for a time sufficient to wet the surface of the steel and to form an alloy with it. When the reaction has reached a certain point, the billet is drawn up into the tube and the whole carried to a second furnace of the pit type, the pots of which contain the purest commercial copper. The tube and billet is lowered into a crucible; the molten copper rushes in through two openings in the top of the tube, unites with the alloyed area, and fills the mold. The tube is then withdrawn from the crucible and when the copper has set, the chuck, rod and flange are unscrewed, the copper-clad billet is pushed out of the mold, and after the necessary preliminary heating it is rolled to any desired size and shape.

TABLE I.—TENSION TESTS OF COPPER-CLAD AND BARE STEEL RODS.

Specimen.	Diameter, ins.	Yield Point.		Ultimate Strength.		Ratio of Yield Point to Ultimate, per cent.
		Total, lbs.	Lbs. per sq. in.	Total, lbs.	Lbs. per sq. in.	
Bare steel, annealed.	0.381	4,800	42,165	6,200	54,386	77.09
	0.380	4,650	41,150	6,000	53,098	77.50
	0.380	4,580	40,531	5,870	51,947	78.19
	0.372	4,400	40,515	6,150	56,029	71.56
Copper-clad steel, annealed.	0.378	5,080	45,279	6,020	53,750	82.72
	0.380	5,130	45,399	6,019	53,265	85.23
	0.376	5,350	48,198	6,000	54,054	89.16
	0.379	4,900	43,362	5,980	52,035	81.98
	0.378	5,000	44,643	5,900	52,678	84.74
	0.380	4,920	43,539	5,890	52,124	83.53

The rolling is in general similar to that of steel, and it is interesting to note that notwithstanding the differences between the physical properties of copper and steel, the two metals when welded by this process flow practically as one, and the proportional areas of the copper and the steel remain practically a constant from the larger to the smaller passes.

The physical properties of copper-clad steel are noteworthy. Considering a metal having 40 per cent. of its sectional area copper and 60 per cent. made up of a steel containing not over 0.15 per cent. carbon, 0.40 per cent. manganese, and 0.04 per cent. sulphur and phosphorus, its tensile strength, after the proper treatment, is equal to or closely approximates, and its yield point is greater than that of an all-steel rod of an equal section and a similar composition and treatment. An illustration of this is shown in Table I, which gives results of tension tests of $\frac{3}{8}$-in. copper-clad and bare steel rods, both annealed dead soft, the steel in each coming from the same heat.

The values become the more apparent when a comparison is made with the breaking weight of some commercial wires, thus:

Name.	Diameter, ins.	Breaking Weight, lbs.
Galvanized steel	0.162	1,406
B. B.	0.162	1,250
E. B. B.	0.162	1,140
Copper (H. D.)	0.162	1,237
Copper-clad	0.162	1,874

FIG. 4.—Cross Section of a $5\frac{1}{16}$-in. Steel Billet before Coating with Copper. (× 125.)

These tables tend to show that the ultimate tensile strength of copper-clad steel is not the means of the strengths of the copper and the steel, for the ultimate strength closely approximates, if it does not surpass, that of the all-steel rod. This statement applies also to the yield point; a copper-clad steel, when dead soft, has a yield point which will average 84 per cent. of the ultimate strength.

FIG. 5.—Longitudinal Section of a $5\frac{1}{16}$-in. Steel Billet before Coating with Copper. (× 125.)

The yield point of copper is about one third of its ultimate strength, while that of steel is a variable, but for comparison take the highest ratio given in Table I, 78 per cent.; copper-clad steel, four-tenths of whose sectional area is a metal having a relatively low elastic limit, has a ratio greater than that of a similar steel of the same sectional area treated under like conditions. These high values are to be accounted for in part, perhaps, by the influence of the "first dip" or alloy coat of copper and its effect on the structure of the clad metals, especially on that of the steel. Taking a $\frac{3}{8}$-in. rod and developing the structure at the weld area, it will be

FIG. 6.—Structure of a Steel Billet after Coating with Copper. (× 125.)

noticed that there are certain compounds present (Fig. 3), and these compounds together with the copper must have a far-reaching effect.

In any metal, other things being equal, the finer the grain, the better its physical properties. Starting with this axiom we can find a reason for the high values given by copper-clad steel in a study of its structure. In Figs. 4 and 5 we have photomicrographs of the $5\frac{1}{16}$-in. billet before coating with copper. In Fig. 6 we have the structure of the steel in the copper-clad billet immediately after coating and before any heat treatment or work has been applied. Figs. 7 and 8 show the structure in a longitudinal and a cross section, respectively, of a $\frac{3}{8}$-in. rod rolled from an uncoated $5\frac{1}{16}$-in. steel billet, and Figs. 9 and 10 show similar views

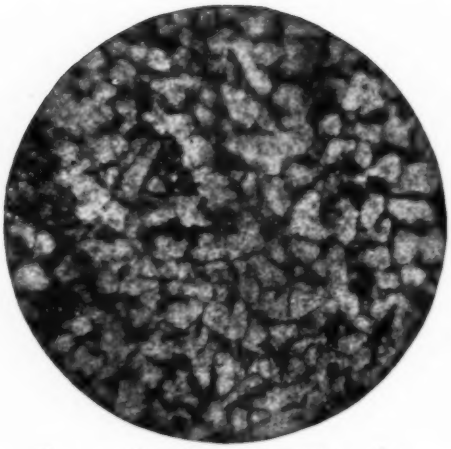


FIG. 7.—Longitudinal Section of a ⅞-in. All-steel Rod. (× 125.)

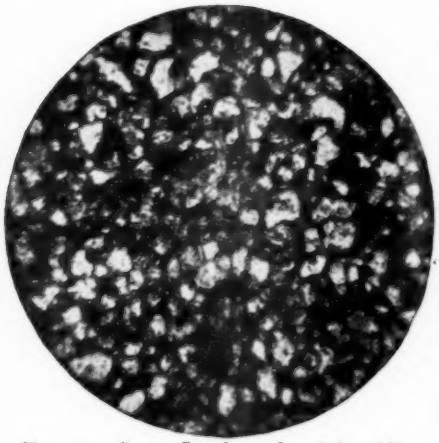


FIG. 8.—Cross Section of a ⅞-in. All-steel Rod. (× 125.)

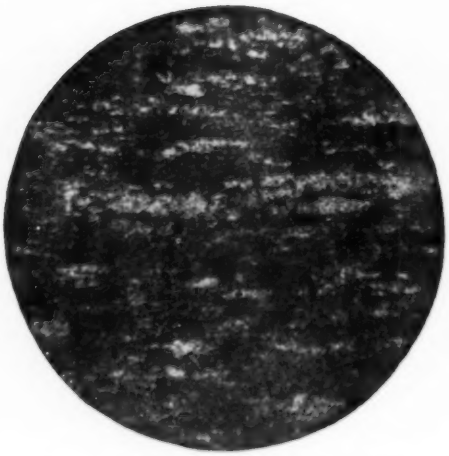


FIG. 9.—Longitudinal Section showing Steel in a ⅞-in. Copper-clad Rod. (× 125.)

FIG. 10.—Cross Section showing Steel in a ⅞-in. Copper-clad Rod. (× 125.)

of the steel in the $\frac{3}{8}$-in. copper-clad rod, all at a magnification of 125 diameters. The difference in structure and the relative coarseness of the all-steel rod as compared with that of the copper-clad rod is at once apparent.

To still further emphasize the fineness of grain of copper-clad steel and the profound influence of the copper upon it, compare the structure of the steel in Fig. 11, which is a photomicrograph of the steel in a $3\frac{13}{16}$-in. copper-clad bar, with that of the $\frac{3}{8}$-in. bare steel rod, Fig. 8, both magnified 125 diameters. The grain of the copper-clad steel is but little coarser than that of the bare steel

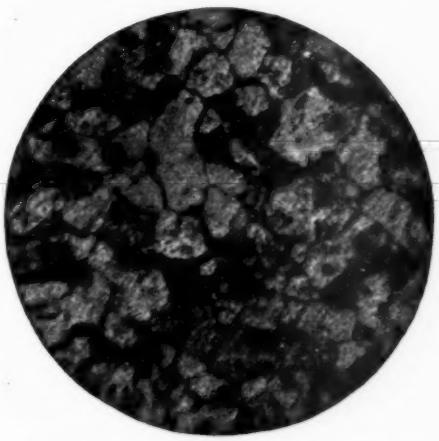


FIG. 11.—Cross Section showing Steel in a $3\frac{13}{16}$-in. Copper-clad Bar. (× 125.)

rod, yet the one is ten times greater in diameter than the other. Further examples of these differences in structure are to be seen in Figs. 12, 13, 14 and 15, which are longitudinal sections, respectively, of the steel in No. 2 B. & S. copper-clad, No. 6 iron gage galvanized steel, No. 6 B.B., and No. 6 E.B.B. wires at a magnification of 200 diameters.

Copper and steel in the presence of moisture form a couple, and the rusting of the steel proceeds with great rapidity. The resistance to corrosion of copper-clad steel, as far as the copper coating is concerned, is of course the same as that of copper; but, in view of the marked galvanic action set up between copper and steel, it would be assumed that corrosion would quickly occur at

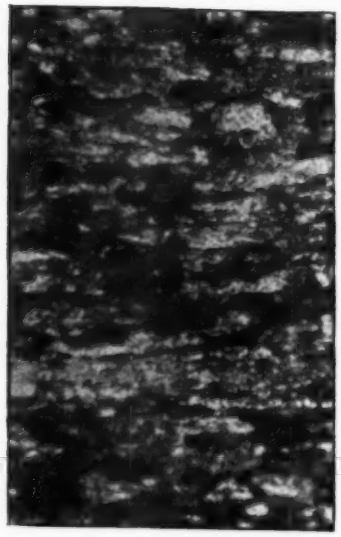


FIG. 12.—Longitudinal Section showing Steel in No. 2 B. & S. Copper-clad Wire. (× 200.)

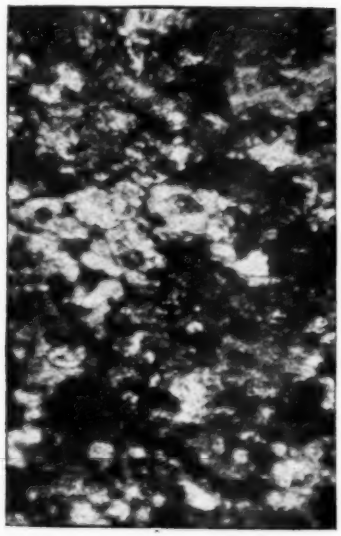


FIG. 13.—Longitudinal Section of No. 6 Galvanized Steel Wire. (× 200.)

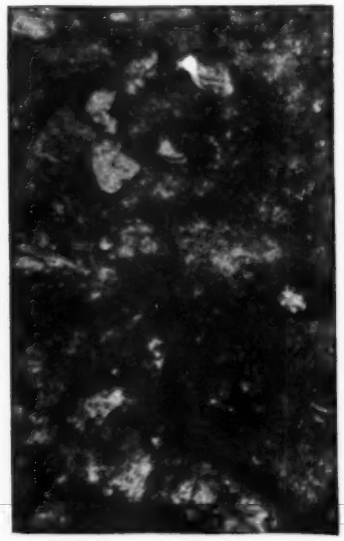


FIG. 14.—Longitudinal Section of No. 6 B. B. Wire. (× 200.)

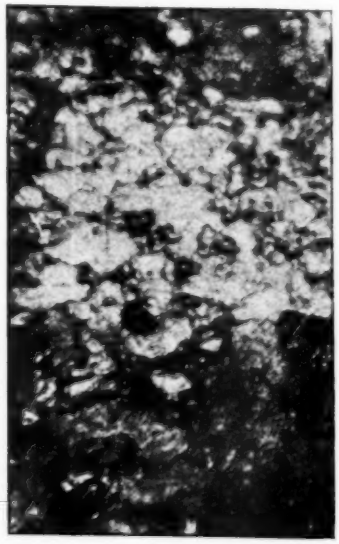


FIG. 15.—Longitudinal Section of No. 6 E. B. B. Wire. (× 200.)

the exposed ends and be a constant and active factor as long as an electrolyte was present, and that this factor would be the more active at the point of union of the two metals than elsewhere. This supposition is not correct, however, for tests on copper-clad rods have shown that when corrosion is set up it begins at the center of the steel instead of at the point of contact of the two metals; while with a copper tube shrunk on a steel rod, exactly the reverse is true. These conditions are illustrated diagrammatically in Fig. 16. In *a*, corrosion sets up at or near the center of the steel and proceeds more or less slowly towards the copper, being more active at the center of the steel and less active at the copper contact, and forming a crater-like cavity, as shown. In *b*, corrosion sets up at the point of contact with the copper and proceeds more

(*a*) Copper-clad Rod. (*b*) Copper-covered Rod.

FIG. 16.

or less rapidly along this contact and through the steel until the latter is gone. These phenomena may be explained on the ground that in copper-clad steel there is a definite union of the copper and steel, and that certain of the products of this union possess properties which retard ionization and do not accelerate corrosion. In the copper-covered rod there is no definite union of the copper and the steel; hence no compounds can be present, and the differences in polarity and potential between copper and steel further ionization and accelerate corrosion.

The uses to which copper-clad steel may be put are many. The most obvious is a wire to be used for electrical and mechanical purposes. The conductivity requirements for electrical use depend directly upon the amount and kind of copper used in the coat. For example, a copper-clad wire, four-tenths of whose sectional area is copper, will have a conductivity as shown in Table II.

TABLE II.—COMPARATIVE WEIGHTS AND RESISTANCES PER 1,000 FT., AND OTHER DATA.

B. & S. Gage Number.	Weight in lbs. per 1,000 ft.		Av. Resistance Int. Ohms per 1,000 ft. at 60° F.		Area in sq. ins., $D^2 \times 0.7854$.	Reciprocal of Area. $\frac{1}{A} = R.$
	Copper-clad.	Copper.	Copper-clad.	Copper.		
0000	594.5	639.8	0.1202	0.04906	0.16619	6.0172
000	471.4	507.3	0.1516	0.06189	0.13177	7.5891
00	373.9	402.4	0.1912	0.07803	0.10452	9.5675
0	296.6	319.2	0.2408	0.09831	0.082907	12.062
1	235.1	253.0	0.3040	0.1241	0.065733	15.213
2	186.4	200.6	0.3835	0.1565	0.052117	19.187
3	147.8	159.1	0.4832	0.1972	0.041331	24.195
4	117.3	126.2	0.6095	0.2488	0.032781	30.505
5	92.92	100.0	0.7688	0.3138	0.025987	38.481
6	73.73	79.35	0.9690	0.3955	0.020612	48.515
7	58.50	62.96	1.221	0.4986	0.016354	61.147
8	46.39	49.92	1.540	0.6288	0.012969	77.109
9	36.77	39.57	1.944	0.7934	0.010279	97.288
10	29.17	31.39	2.449	0.9996	0.0081553	122.62
11	23.11	24.87	3.092	1.262	0.0064611	154.77
12	18.34	19.74	3.898	1.591	0.0051276	195.02
13	14.56	15.67	4.908	2.003	0.0040715	245.61
14	11.54	12.42	6.190	2.527	0.0032271	309.88
15	9.160	9.858	7.802	3.185	0.0025607	390.52
16	7.250	7.802	9.855	4.022	0.0020268	493.38
17	5.765	6.204	12.39	5.059	0.0016117	620.46
18	4.562	4.910	15.66	6.392	0.0012756	783.97
19	3.621	3.897	19.74	8.057	0.0010122	987.92
20	2.877	3.096	24.83	10.14	0.00080425	1243.4

In other words, copper-clad-steel electrical wire has an average conductivity of 40 per cent. of that of the same size copper wire. In telephone work the life of the wire is dependent upon its breaking weight and elastic limit. For a No. 10 copper wire these are respectively 530 and 293 lbs., while for a No. 14 copper-clad wire, they are 760 and 320 lbs. The one weighs 166 and the other 61 lbs. per mile. Comparing copper-clad with galvanized iron telephone wire, a much smaller size of the former may be used for the same ohmic resistance, as shown by the following table:

Wire.	Diameter, ins.	Ohms per mile, at 68° F.	Weight per mile, lbs.
E. B. B.	0.134	18.83	250
B. B.	0.134	22.04	250
Copper-clad	0.134	7.50	266

Both copper and steel possess certain disadvantages for line work. Copper has a low elastic limit and a low tensile strength as compared to its unit weight. These give it a marked tendency to stretch, and every stretch reduces section, conductivity and life. Steel has a low conductivity and is subject to a more or less rapid corrosion. Copper-clad wire has the strength of steel and the durability of copper. Therefore, where a high tensile strength and a resistance to corrosion is an essential and a good conductivity is desirable,—as, for example, in power transmission requiring long spans,—its value is apparent.

For mechanical purposes, such as bridge work, derrick guys, rigging, springs, rounds of all sizes suitable for anchor bolts, pump rods, etc., where resistance to corrosion combined with a high tensile strength is an essential, copper-clad steel is admirably adapted, since steel having any desired physical qualities may be used as the core. For large structural shapes it is questionable whether this material will ever have a commercial use, but for light shapes suitable for skylight and similar work its value is obvious. It is non-corrodible and possesses the strength of steel.

DISCUSSION.

The President. THE PRESIDENT.—This is indeed a very interesting paper. The fact that two billets of two dissimilar metals, or a wire of two dissimilar metals, will draw out as one metal, has long been known. My impression is that that is one of the ways in which very small wires have been made for perhaps a century. Very thin wires have been made by drawing out a compound billet of which the interior is composed of, let us say, platinum, and the outside is composed of another metal, say silver. After drawing out a billet of that kind, the silver may be dissolved off the outside of the wire, and in that way a platinum wire of an extraordinarily small section may be obtained. This particular feature is very interesting although not absolutely novel; but other features of the subject presented to us are quite extraordinary. The paper is before you for discussion.

Mr. Linder. MR. OSCAR LINDER.—I should like to ask what practical use has been made of copper-clad wire in telephone practice.

Mr. Tassin. MR. WIRT TASSIN.—There are many thousand miles of it in use. It has been employed for drop wires in telephone practice. I know of about 40,000 miles of it in use for telegraph and signal purposes.

Mr. Linder. MR. LINDER.—How does the price of copper-clad wire compare with the price of pure steel and of pure copper?

Mr. Tassin. MR. TASSIN.—The price is slightly lower than that of pure copper wire, and, of course, considerably higher than that of steel wire.

The President. THE PRESIDENT.—When this process of making copper-clad wire is further developed, will it not admit of a further reduction in cost? The present cost may approximate that of copper, but is there any necessity why the cost should always remain as high as at present? I am not talking about price, but about cost.

Mr. Tassin. MR. TASSIN.—With the development of any new industry there is an opportunity for reduction of cost; and in this case it is bound to come, as this is a new industry.

MR. J. R. CAIN.—I should like to ask what difference there is in microscopic structure between the steel at the point of union or contact with the copper, and at the center of the bar, with respect to the carbon condition. **Mr. Cain.**

MR. TASSIN.—The structure of the steel is uniform throughout. There is less carbon immediately adjacent to the copper than there is in the center of the bar, but there are certain other features of the structure that are practically impossible to describe, for reasons which will be familiar to any one acquainted with metallographic work. Exactly what the influence of copper is, and what these copper-iron alloys are, can only be determined after a large amount of experimental work. The fine fibrous structure of steel is characteristic of all copper-clad steel. **Mr. Tassin.**

MR. MONT SCHUYLER.—As I understand it, the figures on cost are based on pure copper and copper-clad wires of equal diameter, and not on wires of equal resistance. **Mr. Schuyler.**

MR. TASSIN.—The comparative cost referred to is per pound. **Mr. Tassin.**

MR. SCHUYLER.—Then on the basis of equal current-carrying capacity, the cost of copper-clad wire would be considerably higher than the cost of pure copper wire. **Mr. Schuyler.**

MR. LEONARD WALDO.—The modulus of elasticity as applied to a combination of copper and steel presents no little difficulty. Steel unfortunately is a metal which hardens by chilling, while copper is a metal which softens by chilling. Here we have a combination of the two metals. It is questionable, to say the least, whether copper has a true modulus of elasticity. Those of us who have occasion to draw many million pounds of copper know that by drawing copper exceedingly hard the elongation is reduced to about 0.1 to 0.2 per cent., and that the actual stretch and set of copper wire under moderate stress is not recognizable by any instrument in ordinary use. Therefore, with all due respect to the conclusions advanced in the two papers on the modulus of elasticity of copper published in the Proceedings of the American Institute of Electrical Engineers within the last ten years, the moduli stated therein are subject to reasonable doubt. When it comes to the actual modulus of elasticity of this copper-clad wire, it is found to be just about what one would expect from the mild steel used in the core, namely, approximately 18,000,000, which is very generally stated as the modulus of hard- **Mr. Waldo.**

Mr. Waldo. drawn copper. Unfortunately there is a difference in the sustaining power of the moduli of copper and steel, for if a steel and a hard-drawn copper wire are supported over the same span, and under the same conditions, the copper will ultimately sag, while the steel will remain taut, although the moduli of elasticity are stated to be the same. It is also to be noted that the tensile strength of copper diminishes with time and exposure.

That leads me to another thought. It seems to me that no one factor is of as much importance to the engineer in the preparation of specifications as a clear understanding of the term "modulus of elasticity" as applied to the material under consideration. Of course, in the use of the term "modulus" I do not mean the general modulus, but I mean what we all recognize as Young's modulus. Would it not be well for this Society to appoint a committee to define the modulus of elasticity for our own use, whether it be accepted in outer circles or not? I would suggest that this is a case where the progress of mechanical art requires some accurate definition, and where for the first time, so far as I know, the modulus of elasticity of steel and the so-called modulus of elasticity of copper come squarely in contact for purposes of comparison.

President. THE PRESIDENT.—It seems to me that in the case of a single bar which is composed jointly of a substance of low elastic limit and a substance of higher elastic limit, and in which there exist copper and iron alloys of unknown and unconjecturable composition, the way in which the stress is applied from the point of contact is a very important matter. Might not the mode of application of the stress be a large factor in accounting for the very high elastic limits recorded? In this case we have a condition different from that in ordinary metals, inasmuch as the stress is transmitted through a metal of low elastic limit to a material of higher elastic limit. That seems to me to be a feature which deserves careful investigation.

I shall be glad to entertain a motion from Mr. Waldo that the question of the appointment of such a committee as he suggests be referred to the Executive Committee.

Mr. Waldo. MR. WALDO.—I am not prepared to offer such a motion at this time, but I may do so later.

SOME RECENT TESTS OF CAST IRON.

By Alexander E. Outerbridge, Jr.

In the Proceedings of the American Society for Testing Materials, 1903, Volume III, page 216, will be found a paper by the writer on "The Importance of Adopting Standard Sizes of Test Bars for Determining the Strength of Cast Iron," the length of the title being somewhat disproportionate to the brevity of the article.

Attention was called therein to the extraordinary variation in the physical properties, such as strength, hardness, softness, ductility, density, size of grain or "fracture," etc., of test bars or other castings of different thicknesses, poured from one ladle of molten iron, due to differences in the rate of cooling of the metal. No comparable variations, caused in this way, exist with other metals, such as the non-ferrous alloys, or even with steel (except in a minor degree); and it is no exaggeration to say that the rate of cooling of gray cast iron exerts as important an influence in determining its physical properties as does variation of its chemical constituents, within, of course, certain wide limits.

In the paper referred to, four hypothetical cases were cited in illustration of this dictum and several actual tests were recorded. Some of these records were of experiments made by the writer over twenty years ago, while others were of more modern date. Some of them showed the difference in fracture, strength, density, etc., between sections cut from the center and sections cut from near the surface of comparatively large masses of metal. Others showed remarkable differences in tensile strength between round bars of different diameters in the rough, cast from one ladle, and turned to different dimensions. The following conclusions were drawn from these tests: "The rate of cooling of cast iron from the fluid to the solid state is such an important factor in determining the physical properties of the metal, that it is just as necessary to know the dimensions of the test bars as it is to know the chemical composition. For the same reason, it is equally desirable that standard sizes of test bars should be adopted which would be suitable for different grades of iron."

TABLE I.—TENSILE TESTS OF CAST IRON.

Test No.	Dimensions of Bars as Cast, ins	Dimensions of Bars as Machined.			Ultimate Strength of Bars.			Remarks.
		Length, ins.	Diam., ins.	Area, sq. ins.	Total, lbs.	Lbs. per sq. in.	Average, lbs. per sq. in.	
2269	1×1×15	2.0	0.505	0.2	5,400	27,000	27,000	Poured from one ladle; cast March 29, 1910
2270	1×1×15	2.0	0.505	0.2	5,400	27,000		
2271	¾×¾×15	2.0	0.505	0.2	5,900	29,500	29,250	
2272	¾×¾×15	2.0	0.505	0.2	5,800	29,000		
2273	1×1×15	0.75	0.505	0.2	7,000	35,000	36,050	" " " " " April 1, 1910
2274	1×1×15	0.75	0.504	0.1995	7,400	37,100		
2275	¾×¾×15	0.75	0.505	0.2	8,500	42,500	41,750	
2276	¾×¾×15	0.75	0.505	0.2	8,200	41,000		
2299	1×1×15	0.75	0.505	0.2	5,200	26,000	25,000	" " " " " April 5, 1910
2300	1×1×15	0.75	0.505	0.2	4,800	24,000		
2301	¾×¾×15	0.75	0.505	0.2	5,300	26,500	27,500	
2302	¾×¾×15	0.75	0.505	0.2	5,700	28,500		
2284	1×1×15	0.75	0.505	0.2	5,800	29,000	30,500	" " " " " April 9, 1910
2285	1×1×15	0.75	0.505	0.2	6,400	32,000		
2286	¾×¾×15	0.75	0.505	0.2	7,400	37,000	34,750	
2287	¾×¾×15	0.75	0.505	0.2	6,500	32,500		
2288	1×1×15	0.75	0.505	0.2	5,400	27,000	27,000	" " " " " April 12, 1910
2289	1×1×15	0.75	0.505	0.2	5,400	27,000		
2290	¾×¾×15	0.75	0.505	0.2	6,500	32,500	32,250	
2291	¾×¾×15	0.75	0.505	0.2	6,400	32,000		
2303	1×1×15	0.75	0.505	0.2	6,900	34,500	35,000	" " " " " April 21, 1910
2304	1×1×15	0.75	0.505	0.2	7,100	35,500		
2305	¾×¾×15	0.75	0.505	0.2	8,500	42,500	42,500	
2306	¾×¾×15	0.75	0.505	0.2	8,500	42,500		

Since that time some progress has been made in this country towards the standardization of cast-iron test bars, largely through the efforts of Dr. Moldenke and a committee of the American Society for Testing Materials, but there is still a lack of uniformity in the practice prevailing in this country and in Europe, which it is hoped may eventually be rectified.

Very recently the writer has had occasion to again observe the operation of the law of rate of cooling of cast iron in test bars varying but slightly in dimensions. In these later experiments the bars were accurately turned to uniform size and pulled on the 100,000-lb. hydraulic testing machine of William Sellers and Company, Incorporated. It happened that a number of experimental castings were required which would show very much higher tensile and transverse strength (the former to range from about 27,000 to 40,000 lbs. per sq. in.) than if cast from ordinary foundry iron, and at the same time should be absolutely free from brittleness or hard spots in any part of the castings, which were only about $\frac{3}{8}$ in. thick in the thinnest portions.

Two test bars, 1 by 1 by 15 ins. and $\frac{3}{4}$ by $\frac{3}{4}$ by 15 ins., were poured from the same ladle as each casting. The object of making two sizes of test bars varying only $\frac{1}{4}$ in. in lateral dimensions, was to approximate as closely as possible the cooling conditions existing in the castings, which varied in thickness. The larger bars were broken transversely in a testing machine, using a span of 12 ins. Then one of the broken pieces from each transverse test and each of the smaller bars were turned to a diameter of 0.505 in. between threaded ends and pulled in the 100,000-lb. testing machine. The smaller bars were not subjected to the transverse test. Only tensile tests are recorded herein, and all represent tests of different bars, not duplicate tests of any single bar.

The ratio between the transverse strength of a bar 1 in. square, not machined, tested on a 12-in. span, and the tensile strength of the same bar machined, is about one to ten with ordinary foundry iron, about one to eleven with stronger iron, and about one to twelve with very strong iron.

The following interesting points may be noted:

1. The uniformity of tensile strength of different bars of the same dimensions cast from one ladle of iron.

2. Invariably the smaller test bars ($\frac{3}{4}$ in. square) of any series,

if free from flaws, show higher tensile strength than the larger bars (1 in. square) cast from the same ladles, thus fully corroborating the observations previously recorded in 1903.

3. In machining the test bars, it was observed that the "chips" from the bars of the stronger metals (both from those 1 in. square and those $\frac{3}{4}$ in. square), instead of breaking off "short" like ordinary cast iron, were quite "curly" like soft steel or wrought iron turnings.

4. In all cases save one, the metal of the castings in the thinnest section ($\frac{3}{8}$ in.) was entirely free from "chill," or mottled iron, and was readily machinable. In the exceptional instance the metal was perfectly gray in the test bars and in the castings themselves, except in the thinnest portions, where it was almost white, due to more rapid cooling of these very thin walls.

A study of the table of tests (see Table I) will show that the minimum increase in the average tensile strength of the two test bars $\frac{3}{4}$ in. square, over the average tensile strength of the two bars 1 in. square, cast from the same ladle and turned to the same diameter, is 2,250 lbs. per sq. in. The maximum increase under like conditions is 7,500 lbs. per sq. in.

It is certainly remarkable that differences so large should occur between bars differing so little in dimensions, cast from one ladle, and presumably of uniform mixture of iron. It shows how very sensitive the metal is to cooling influences, and again reveals the importance of adopting standard sizes of bars for tests of cast iron.

TESTS OF CAST-IRON ARBITRATION TEST BARS.

By C. D. Mathews.

In accordance with the suggestion of Sub-Committee Ia of the International Association for Testing Materials, the writer submits the result of a series of tests on Cast-Iron Arbitration Test Bars. Since a separately cast test bar of round section is generally recognized as best showing the strength and quality of the metal going into iron castings, these tests were carried out to determine only the length of span best suited for satisfactory and uniform results.

The test bars, $1\frac{1}{4}$ ins. in diameter and 26 ins. long, were cast separately on end in dry-sand molds. Nine sets of bars were taken from different melts to represent the three grades or classes of ordinary iron, viz., silicon 1.50, 2.00, and 2.50 per cent. To insure uniformity, the iron representing each set was first taken from the cupola in a four-ton ladle, and from this ladle three hand-ladles were taken to pour each set.

From each set three transverse tests were made on supports 12, 18, and 24 ins. apart. A variation in diameter of bars from 1.23 to 1.25 ins. was noted and the values corrected for a diameter of 1.25 ins. No correction was made for deflection. Three tensile tests were made from each set for comparison, the test-pieces being taken from broken sections of bars from the transverse test, turned to 0.80 in. diameter, with the ends threaded for grips. A number of analyses were made in order to determine if any variation in strength was caused by, or could be attributed to any difference in composition.

The results of the transverse and tensile tests are given in Tables I, II, and III, and the respective analyses in Tables I*a*, II*a*, and III*a*.

Considerable variation in strength is found, even in iron from the same ladle, though the average results are quite uniform in relative proportion to the span and the tensile strength.

TABLE I.—TESTS OF CAST-IRON ARBITRATION TEST BARS.

Silicon = 1.50 per cent.

Set No.	Test No.	Transverse Test.						Tensile Strength, lbs. per sq. in.
		12-in. Span.		18-in. Span.		24-in. Span.		
		Breaking Load, lbs.	Defl., ins.	Breaking Load, lbs.	Defl., ins.	Breaking Load, lbs.	Defl., ins.	
1	1	2,760	0.13	1,900	0.20	1,385	0.32	25,600
	2	3,105	0.14	2,120	0.24	1,540	0 35	26,400
	3	2,885	0.13	1,980	0.22	1,485	0.34	26,700
2	1	3,015	0.14	2,045	0.24	1,520	0.37	24,280
	2	3,475	0.13	1,995	0.24	1,535	0.37	24,600
	3	3,095	0.13	2,045	0.24	1,510	0.35	24,540
3	1	2,920	0.14	1,735	0.24	1,265	0.31	26,000
	2	2,955	0.14	1,730	0.25	1,325	0.32	26,060
	3	2,790	0.13	1,870	0.26	1,270	0.30	26,160
Average....		3,000	0.13	1,935	0.24	1,425	0.34	25,600
Low		2,760	0.13	1,730	0.20	1,265	0.30	24,280
High		3,475	0.14	2,120	0.26	1,540	0.37	26,700

TABLE Ia.—ANALYSES OF CAST IRON IN TABLE I.

Set No.	Test No.	Sil.	Sul.	Phos.	Mang.	Comb. Carbon.	Graph. Carbon.	Total Carbon.
1	1	1.65	0.10	0.82	0.46	0.78	2.80	3.58
	2	1.65	0.10	0.80	0.45	0.80	2.80	3.60
	3	1.64	0.10	0.83	0.42	0.80	2.76	3.56
2	1	1.56	0.11	0.80	0.42	1.02	2.68	3.70
	2	1.59	0.115	0.77	0.44	1.04	2.68	3.72
	3	1.59	0.11	0.76	0.45	1.04	2.74	3 78
3	1	1.51	0.11	0.82	0.44	0.88	2.86	3.74
	2	1.49	0.11	0.80	0.45	0.84	2.84	3.68
	3	1.47	0.105	0.78	0.42	0.86	2.86	3.72

All values are given in per cent.

TABLE II.—TESTS OF CAST-IRON ARBITRATION TEST BARS.

Silicon = 2.00 per cent.

Set No.	Test No.	Transverse Test.						Tensile Strength, lbs. per sq. in.
		12-in. Span.		18-in. Span.		24-in. Span.		
		Breaking Load, lbs.	Defl., ins.	Breaking Load, lbs.	Defl., ins.	Breaking Load, lbs.	Defl., ins.	
4	1	2,960	0.14	1,760	0.24	1,360	0.36	24,200
	2	3,285	0.15	1,770	0.25	1,180	0.34	24,620
	3	2,980	0.13	1,660	0.23	1,190	0.32	25,000
5	1	2,625	0.13	1,850	0.22	1,300	0.32	23,920
	2	2,695	0.12	1,850	0.21	1,310	0.33	23,580
	3	2,695	0.12	1,840	0.22	1,300	0.32	23,800
6	1	2,700	0.13	1,975	0.27	1,200	0.30	24,700
	2	3,015	0.13	1,905	0.24	1,260	0.32	24,540
	3	3,160	0.14	1,925	0.24	1,280	0.34	25,000
Average....		2,900	0.13	1,835	0.24	1,265	0.33	24,370
Low		2,625	0.12	1,660	0.21	1,180	0.30	23,580
High		3,285	0.15	1,975	0.27	1,360	0.36	25,000

TABLE II*a*.—ANALYSES OF CAST IRON IN TABLE II.

Set No.	Test No.	Sil.	Sul.	Phos.	Mang.	Comb. Carbon.	Graph. Carbon.	Total Carbon.
4	1	2.08	0.08	0.80	0.47	0.74	2.80	3.54
	2	2.12	0.075	0.80	0.49	0.70	2.84	3.54
	3	2.10	0.08	0.84	0.46	0.70	2.80	3.50
5	1	1.94	0.075	0.80	0.50	0.68	3.08	3.76
	2	1.95	0.07	0.80	0.52	0.70	3.02	3.72
	3	1.93	0.07	0.76	0.49	0.70	3.06	3.76
6	1	1.87	0.065	0.82	0.44	0.70	2.88	3.58
	2	1.89	0.065	0.76	0.42	0.73	2.90	3.63
	3	1.89	0.065	0.78	0.45	0.75	2.80	3.55

All values are given in per cent.

TABLE III.—TESTS OF CAST-IRON ARBITRATION TEST BARS.

Silicon = 2.50 per cent.

Set No.	Test No.	Transverse Test.						Tensile Strength, lbs. per sq. in.
		12-in. Span.		18-in. Span.		24-in. Span.		
		Breaking Load, lbs.	Defl., ins.	Breaking Load, lbs.	Defl., ins.	Breaking Load, lbs.	Defl., ins.	
7	1	2,695	0.14	2,225	0.25	1,415	0.43	24,000
	2	3,030	0.14	1,995	0.23	1,495	0.48	24,360
	3	2,985	0.15	1,860	0.23	1,155	0.35	25,000
8	1	3,065	0.15	1,900	0.26	1,565	0.43	24,000
	2	2,765	0.13	1,910	0.25	1,260	0.36	24,400
	3	2,765	0.14	1,685	0.21	1,460	0.40	26,500
9	1	2,825	0.13	1, 75	0.22	1,425	0.43	24,580
	2	2,910	0.14	1,905	0.26	1,315	0.38	25,100
	3	2,880	0.14	1,795	0.23	1,510	0.44	24,200
Average....		2,880	0.14	1,905	0.24	1,400	0.41	24,660
Low.....		2,695	0.13	1,685	0.21	1,155	0.35	24,000
High.....		3,065	0.15	2,225	0.26	1,565	0.48	26,500

TABLE III*a*.—ANALYSES OF CAST IRON IN TABLE III.

Set No.	Test No.	Sil.	Sul.	Phos.	Mang.	Comb. Carbon.	Graph. Carbon.	Total Carbon.
7	1	2.65	0.08	0.70	0.65	0.75	3.02	3.77
	2	2.67	0.075	0.72	0.64	0.75	3.00	3.75
	3	2.68	0.08	0.74	0.67	0.75	3.02	3.77
8	1	2.44	0.08	0.87	0.39	0.70	2.88	3.58
	2	2.46	0.08	0.87	0.41	0.70	2.88	3.58
	3	2.44	0.08	0.85	0.42	0.70	2.94	3.64
9	1	2.37	0.08	0.88	0.36	0.74	2.78	3.52
	2	2.36	0.075	0.86	0.40	0.76	2.82	3.58
	3	2.34	0.075	0.85	0.38	0.75	2.84	3.59

All values are given in per cent.

TABLE IV.—MODULI OF RUPTURE.

Pounds per square inch.

Silicon, per cent.	Span.			Remarks.
	12 ins.	18 ins.	24 ins.	
1.50	47,100	45,600	44,700	Average of 9 bars.
2.00	45,500	43,200	39,700	" " 9 "
2.50	45,200	44,900	44,000	" " 9 "
1.50	43,300	40,700	39,700	Lowest of 9 bars.
2.00	41,200	39,100	37,100	" " 9 "
2.50	42,300	39,700	36,300	" " 9 "
1.50	54,600	49,900	48,400	Highest of 9 bars.
2.00	51,600	46,500	42,700	" " 9 "
2.50	48,100	52,400	49,200	" " 9 "

In making a comparison of results, it is best to consider the strength as shown by the modulus of rupture. This should theoretically be the same for the same iron, irrespective of the length of span. As a matter of fact, however, it is not.

Table IV shows a summary of the results by comparing the moduli of rupture, giving the average, lowest, and highest for each grade of iron.

From the above it will be noted that while the average results are fairly uniform, the highest average is shown on the 12-in. span and the lowest on the 24-in. span, for each of the three grades of iron. Taking the extreme variation, it is seen that the highest values were obtained on the 12-in. span for 1.50 and 2.00 per cent. silicon, and on the 18-in. span for 2.50 per cent. silicon; the lowest results were all obtained on the 24-in. span. This would seem to indicate that a 12-in. bar is too stiff, and a 24-in. bar too weak, for satisfactory or uniform results. The conclusion would therefore be that the length of span best suited for testing the $1\frac{1}{4}$-in. bar is somewhere between 12 and 24 ins.

With the idea of possibly determining this point, an additional set of forty bars $1\frac{1}{4}$ ins. in diameter and 26 ins. long, as before, were cast from the same mixture of 2.00 per cent. silicon iron, ten bars each being tested on supports 14, 16, 18, and 20 ins. apart. The results of the test are given in Table V; the analysis of metal is given in Table V*a*.

TABLE V.—TRANSVERSE TESTS OF CAST-IRON ARBITRATION TEST BARS.

Breaking Load in Pounds.

Grade of Iron.	Test No.	Span.			
		14 ins.	16 ins.	18 ins.	20 ins.
2.00 per cent. Silicon.	1	2,570	2,200	1,875	1,705
	2	2,500	2,150	1,925	1,900
	3	2,425	2,200	.....*	1,705
	4	2,465	2,030	.....*	1,825
	5	2,340	2,150	1,925	1,715
	6	2,355	2,165	1,775	1,680
	7	2,570	2,160	1,880	1,800
	8	2,425	2,200	2,100	1,670
	9	2,340	2,025	1,950	1,600
	10	2,530	2,085	1,830	1,600
Average		2,450	2,135	1,900	1,720
Low		2,340	2,025	1,785	1,600
High		2,570	2,200	2,100	1,900

TABLE Va.—ANALYSIS OF CAST IRON IN TABLE V.

Silicon	1.90 per cent.
Sulphur	0.08 " "
Phosphorus	0.75 " "
Manganese	0.65 " "
Combined Carbon	0.55 " "
Graphitic Carbon	3.10 " "
Total Carbon	3.65 " "

A summary of these results by comparing the moduli of rupture is given in Table VI.

TABLE VI.—MODULI OF RUPTURE.

Pounds per square inch.

	Span.			
	14 ins.	16 ins.	18 ins.	20 ins.
Average	44,000	43,800	43,800	44,100
Low	42,000	41,500	41,200	41,000
High	46,100	45,100	48,500	48,700

These results are quite uniform and would seem to leave it optional as to which should be considered the length of span best suited. Judging from the writer's experience, it is probable that

* Defective bar

16 or 18 ins. would prove equally satisfactory, and either preferable to a greater or less distance.

As the tensile tests were all made on pieces of the same section, cast under the same condition, they offer a reliable means of comparison with the transverse strength at different spans. The results show the following approximate relationship:

Tensile strength	=	8.5	times	transverse strength	at	12	ins.
"	"	= 13	"	"	"	"	18	"
"	"	= 18	"	"	"	"	24	"

Variations of about 5 per cent. in tensile strength and at least 10 per cent. in transverse strength are to be expected.

DISCUSSION.

Mr. Moldenke. MR. RICHARD MOLDENKE.—In the discussion on the subject of cast iron at the recent Copenhagen Congress of the International Association for Testing Materials, the fact developed that in countries in which tests of cast iron are made, there is what is practically an agreement as to the diameter and the manner of casting the test bars. The best length of the bar is the only point not yet settled. Furthermore, everybody has now come to the conclusion that a casting in itself cannot be fairly represented by a test bar, but only the material that goes into the casting. If we know that the material is right, it is only a question of foundry practice to get the castings right. Now in Italy they are using a test bar $1\frac{1}{4}$ ins. in diameter, on supports 6 ins. apart. In the United States we are using the same test bar on supports 12 ins. apart, and in Germany they are using the same size test bar on supports 24 ins. apart. The suggestion has been made to get everybody interested to make a series of test bars of different lengths, but of the standard diameter and cast in the same way, in order to determine if possible the point at which the bar is neither too long nor too short. If too short it would be artificially too strong, and if too long it would not be sensitive enough to show a slight difference in load. Mr. Wood has prepared a large series of these bars at his works, and the paper in question gives the results of tests, which seem to indicate that the right point would lie somewhere between 16 and 18 ins. If in other countries similar conclusions are reached, it should then be possible to fix the length of the test bar by universal agreement. We shall then have the first universal specification governing the testing of cast iron.

Mr. Wood. MR. WALTER WOOD.—I think some of us will recollect a meeting seven, eight or nine years ago when it appeared that we were as wide apart in America in regard to test bars as in some countries abroad, and it was only after considerable discussion that there originated what is known as the "Arbitration Test Bar." That bar is now being adopted in Germany and Italy, and the English had nothing to say against it at Copenhagen. I think it will not be more than a year or two before we shall have reached a final conclusion on this question.

UNEVENLY CHILLED AND UNTRUE CAR WHEELS.

By Thomas D. West.

It is generally known by those familiar with the manufacture and use of chilled car wheels that only a very small percentage of them are evenly chilled. The writer was informed by our highly esteemed late president, Dr. C. B. Dudley, that in the examination of a large number of broken wheels at Altoona, fully seventy per cent. showed variations in the depth of chill. Unfortunately for the railroads, the evenness of chill around wheels is a quality which defies inspection, so that the buyer purchases "a pig in a poke" as far as knowledge of this point is concerned.

An uneven depth of chill around car wheels is a serious evil. It weakens a wheel just as similar defects weaken chilled rolls, and rolls often snap in two under loads that would have had little effect on them were they chilled to an even depth. The chief cause of this weakness lies in the great difference in strength and contraction of the same iron when in a gray state and in the chilled form.

First, as to the question of strength. Of two casts from the same ladle, the one gray and the other chilled or of an all-white fracture (which means that the carbon is almost entirely in the combined form), the latter generally possesses but little over half the strength of the former. The strength of the white or chilled iron varies according to the class of iron used, that coming from a burnt or oxidized iron being the weakest and that from charcoal iron the strongest. As far as the strength is concerned, therefore, compelling the iron to take the white or chilled form is a necessary evil and often a serious one, especially if the depth of chill is uneven, as it is in the great majority of car wheels cast to-day.

Secondly, in considering the relative contraction of chilled and gray iron cast from the same ladle of metal, we find that the former contracts about as much again as the latter in metals such as Nos. 4 and 5, Table I. The bars used by the writer in making these tests were about $1\frac{1}{2}$ ins. square by 24 ins. long. Fig. 1* shows the plan

*Acknowledgment is hereby made to *The Iron Age* for the cuts used in this paper.—Ed.

of molds used; the sand bars were cast in the space P and the chilled bars in N. The one sand cope covered both molds; each mold had a gate at the center, and was poured from the same basin.

If it were not for the fact that the chilled crust of a car wheel or other casting obtains considerable of its contraction before the body of gray iron, which is generally in a liquid state after the

TABLE I.—CONTRACTION TESTS OF CHILLED AND GRAY IRON.
(Test bars, 1½ ins. square by 24 ins. long.)

Heat No.	Character of Metal Tested.	Contraction of Chilled Iron, ins.	Contraction of Gray Iron, ins.
1	Ferro-silicon	0.270	0.240
2	Foundry iron	0.262	0.205
3	Bessemer iron	0.271	0.211
4	Gray iron with 15 per cent. steel	0.322	0.227
5	Charcoal iron	0.446	0.229

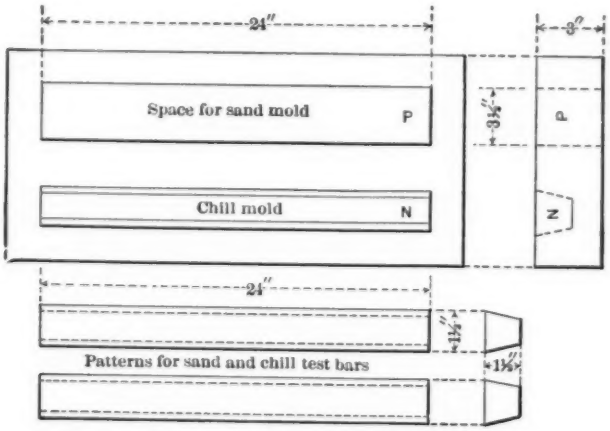


FIG. 1.—Sand and Chill Molds.

chilled crust has solidified, it would be a hazardous undertaking to make any casting having a chilled crust and gray interior. Nevertheless, owing to the difference of contraction mentioned above, there must exist greater internal stresses in a chilled car wheel than if the same casting of gray iron were cooled under normal conditions.

The writer is convinced that the present methods of casting are responsible for not only unevenly chilled, but also for untruly

round car wheels. Recognizing the importance of tests on the roundness of tread of chilled car wheels, he succeeded in obtaining data upon such tests through the courtesies of Mr. S. K. Dickerson, Assistant Superintendent of Motive Power, and Mr. H. E. Smith, Engineer of Tests, of the Lake Shore and Michigan Southern Railway Company.

To make these tests six pairs of wheels cast by different founders were selected. An axle with a wheel pressed on each end was placed in a lathe, and the centers were firmly pressed. The wheels were then hand-turned. This done, the tread was divided into eight sections, each the same distance from the flat edge, and a specially constructed micrometer used to discover any variations in the roundness. All the testing was done with great care and precision.

The tests are illustrated in Fig. 2. The dotted line in each diagram is a circle through that point on the tread having the smallest radius, and is assumed as the datum line. In plotting the diagram, the variations from this datum line have been multiplied by five, in order to emphasize the irregularity of the tread. It is to be understood, however, that the figures given are the actual variations in the radii of the wheels from the datum circle.

The results of a majority of these tests certainly demonstrate the necessity of improvement in the roundness of wheels as well as obtaining an even depth of chill, and show the importance of testing the roundness of car wheels. The writer is not aware of any regular tests of this kind being made by the railroads, but believes that if they were made with the present make of wheels, only a very small percentage would pass satisfactorily. Such tests could readily and cheaply be made before the wheels are bored by setting an internally-turned iron ring over the tread. There are, of course, other plans which could be used, but the ring should answer the purpose in many cases.

While the wheels are undoubtedly weakened by the uneven depth of chill and have therefore a shorter life, their lack of roundness also prevents smooth running and must cause some vibration or pounding which greatly aids in creating fractures or breaks in the rails. This pounding effect of flat wheels has been accurately and scientifically demonstrated.

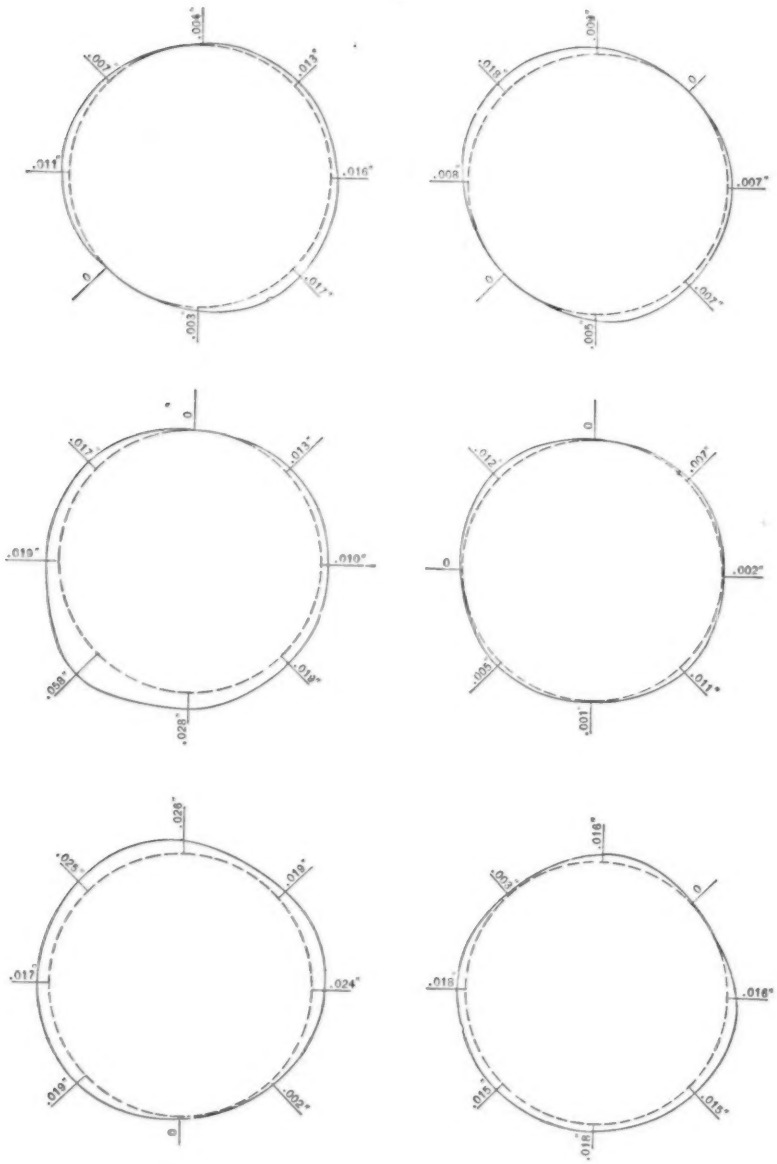


FIG. 2.—Irregularity in the Roundness of Present-Day Chilled Car Wheels.

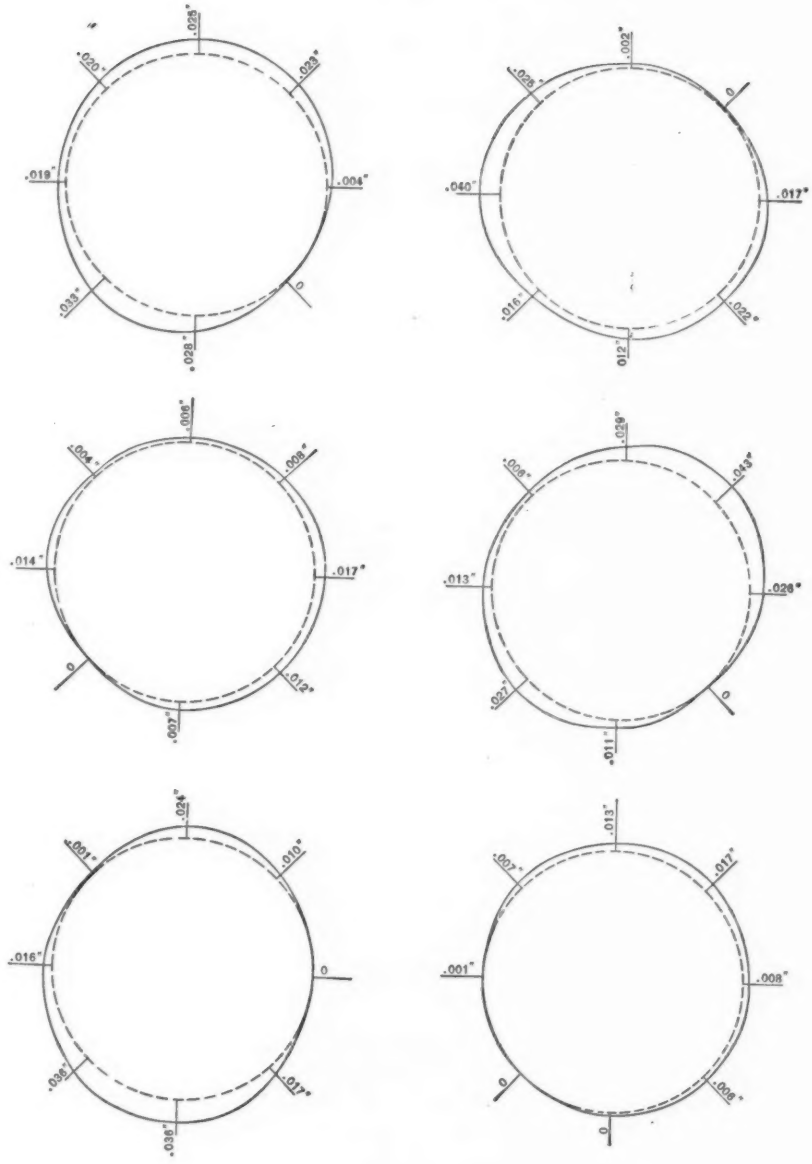


FIG. 2 (*Continued*).—Irregularity in the Roundness of Present-Day Chilled Car Wheels.

The longer any chilled body remains in contact with the chiller, the deeper chill will it possess. Therefore, any factor which tends to prevent the chilled crust from contracting away evenly from the surface of the chiller is a cause of unevenly chilled castings, and also serves to aid the making of untrue wheels.

The writer has, after much study, devised a method of casting which will assure evenly chilled and truly round car wheels. (See *The Iron Age*, Aug. 5, 1909.) Since the publication of this article, the writer has made improvements which allow the outer edge of the flange to be of the form now required by the Master Car Builders' Specifications. This change permits railroads obtaining wheels cast by this method to meet their specifications for form in every respect.

The thermal and drop tests to which chilled car wheels are now subjected define in a measure what qualifications any special lot of ninety-nine or ninety-eight wheels must possess, but is not the present uncertainty of obtaining an even depth of chill one that could often shake faith in the accepted lot? It is therefore essential to know positively just what any method advancing a remedy for these defects will accomplish.

In the past year the writer has done considerable experimenting with his improved method, the results of which have demonstrated the urgent need of having the chilled crust uniformly "hugged" during its contraction. Those familiar with the manufacture of chilled car wheels know that much study has been devoted to the idea of obtaining what has now been achieved by the writer, and that several different methods have been tried to attain these ends. These methods depend upon the expansion of short arms which are a solid part of the chiller. To see how far these arms will tightly follow up the contracting shell, the writer presents the test illustrated by Fig. 3. A 1- by 2-in. wrought-iron bar 12 ins. long has one end A exposed to the heating influence of liquid metal poured into a basin H, 8 ins. in diameter by 5 ins. deep. The other end F is in contact with a 1-in. board K, which is free to swing about the fulcrum M at one end, while the other end just touches a block at D. A test of this device showed that in five minutes after pouring metal to fill the basin, two fingers could be tightly held on the bar at B, 4 ins. from the edge

of the basin. It required ten minutes before light could be seen through the opening at D, and fifteen minutes to note any heat to reach the end of the iron bar at F.

In a study of this test for purposes of comparison, it is to be remembered that the arm or bar A is fully two-thirds the length of those forming a solid part of the so-called compression chiller. Another point to be kept in mind is that any form of arm devised to obtain a tight hugging contact with the contracting crust, as is

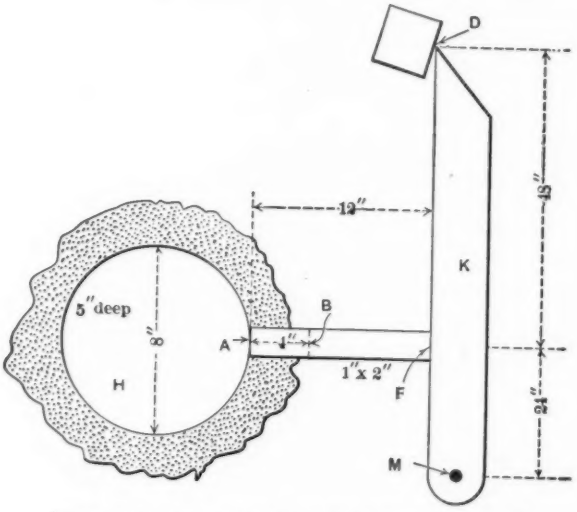


FIG. 3.—Expansion Test for Contraction of Compression Arms.

done in a positive manner with the writer's method, must expand or be forced inward fully $\frac{3}{16}$ in.

Another fact which was brought out in the writer's experiments, and one which he believes is known or fully realized by very few if any experienced car wheel makers, is that the chiller will expand about $\frac{1}{4}$ in. in diameter after pouring the metal. Here we have a movement which is the opposite of contraction and which, in the case of the compression chiller, serves to pull the arms back from the contracting crust more than their expansion can force them inward. This evidently defeats the purpose of having arms to tightly hug the contracting crust, which is necessary to obtain an even depth of chill and true roundness in wheels.

To those who are familiar with the manufacture of car wheels, the importance of the above comparisons is self-evident.

The recent experiments of the writer tender every assurance of his method giving evenly chilled and truly round car wheels. This improvement should greatly encourage the continued use of chilled wheels, no matter what proficiency may be obtained by wrought-iron or steel wheels, comments on the value of which are made by the writer in the article published in *The Iron Age*, referred to herein.

ALUMINATES: THEIR PROPERTIES AND POSSIBILITIES IN CEMENT MANUFACTURE.

By Henry S. Spackman.

The purpose of this paper is to point out the value of combinations of alumina or other sesquioxides with a base, such as lime, as an addition to natural cements, puzzolanic cements, and lime mortars; to show their power of increasing the strength, hardness and hydraulic properties of such mortar-making materials on being added thereto; and to emphasize the views expressed on the commercial value of such additions in a paper on this subject read before the Franklin Institute in February, 1909.

Before considering in detail the various tests showing the effect of such additions, I wish to make clear that the conclusions drawn are not based on the comparatively few tests given in this paper. On the contrary, the tests given are confirmed by hundreds of others of a similar character. Some conception of the thoroughness of the investigation may be gained from the statement that since February, 1908 (at which time separate record books for this aluminate investigation were opened), the numbers used in identifying the briquettes have advanced from 1 to over 30,000. Nor has this investigation been confined to the study of a few samples prepared in the laboratory with special care; on the contrary, the work includes the preparation, manufacture and testing, and the practical use of many lots of aluminate made on a semi-commercial scale in quantities of from ten to twenty tons each. These aluminates were produced under varying manufacturing conditions and from different materials, and they were subject to all the vicissitudes of actual manufacture. And recently the work has included the testing and use of commercial aluminates now being prepared in large quantities and sold to the trade.

While the purpose of this paper, as stated, is to show the results obtained by the addition of aluminates or combinations of sesquioxides and a base to mortar-making materials, I wish, in order to place the matter clearly before you, to first describe

briefly the aluminates of lime alone, which for commercial reasons will probably be given preference as an addition.

Prior to the recent publication by Sheppard and Rankin of their paper, *Binary Systems of Aluminates with Silica, Lime and Magnesia*, there was no definite knowledge as to the number or exact constitution of the several aluminates supposed to be formed by the furnacing together of various mixtures of lime and alumina. It was generally assumed, however, that two, or possibly three, definite compounds existed, corresponding to the formulas $Al_2O_3 \cdot CaO$, $Al_2O_3 \cdot 2CaO$, and $Al_2O_3 \cdot 3CaO$, the existence of the latter in cement, however, being questioned by some authorities. Nor was it certain that these definite lime-alumina compounds were formed in cement in any quantity, the general trend of thought leaning toward the formation of complex compounds of lime, silica, and alumina, or else solid solutions. Still less was known of the exact function of alumina in cement, either in the process of burning or in the subsequent hydration on grinding and mixing with water. In general, however, while alumina was considered valuable as a flux, it was believed to be objectionable in any large quantities, although for commercial reasons, such as the raw materials used, ease of burning, etc., it was considered that it must necessarily be present in cement. Eckels states the general rule that "the percentage of lime being constant, the clinkering temperature decreases with the silica-alumina ratio, while the setting time and ultimate strength of the cement are in inverse proportion to the value of the ratio."

The recent paper by Sheppard and Rankin throws more light on the subject and seems to demonstrate the existence of seven phases of lime-alumina compounds in addition to the two components; these include the four definite compounds: $3CaO \cdot 5Al_2O_3$, $CaO \cdot Al_2O_3$, $5CaO \cdot 3Al_2O_3$, and $3CaO \cdot Al_2O_3$. These investigators also state in their conclusions that of these aluminates it seems probable that only $3CaO \cdot Al_2O_3$ will occur in Portland cement, contradicting the general opinion heretofore held that alumina in Portland cement, if present as a separate compound, was combined with the lime in the ratio of $Al_2O_3 \cdot 2CaO$, which compound according to Sheppard and Rankin does not exist.

In the early laboratory work aluminates were made by molding a mixture of lime and aluminous material into briquettes

and burning them with petroleum coke in a small upright kiln, to which forced draft could be applied if desired. No difficulty was met, however, in burning the aluminates, the temperature required being about that necessary for the burning of cement. Subsequently, aluminates were made in large quantities in the manner formerly used for the manufacture of Portland cement —i. e., by making the mixture into bricks and calcining them in a fixed kiln. Aluminates are now produced for commercial purposes by fusing and then granulating.

One fact has been apparent throughout these investigations, and that is, that when the aluminates are to be used in conjunction with other mortar-making materials, such as limes and cements, as an addition for the purpose of increasing their strength, hydraulic properties, etc., their usefulness seems in no way to be affected by variations in the ratio of base to the acid-acting elements, nor apparently by the temperature of calcination. For, the same raw materials, when mixed with different ratios of lime to the alumina and other acid-acting elements, so that the chemical composition varied through the wide range of from less than one molecule of base to each molecule of acid acting-elements to over three molecules of base to each molecule of acid-acting elements, gave like results on being added to limes and cements. In the same way the temperature of calcination was varied from that just sufficient to expel the volatile elements present to that of complete vitrification, and even fusion, without affecting materially the value of the aluminate as an energizing material; the only necessity seems to be that there shall be sufficient base and sufficient heat to break up any existing compounds in the raw material and render them active—i. e., in condition to react with the chemical components or compounds in the cements to which they are added. Aluminates may also be prepared in other ways than by calcination.

While for the sake of brevity I have spoken of aluminates of lime throughout this paper, it is to be understood that other sesquioxides may replace alumina and other bases may replace lime when they are used as energizing material.

It will be apparent from the above that the aluminate energizers may be readily prepared, and, as far as our knowledge now goes, they require no more care, if not less, in their manufacture, than the materials to which they are to be added. It is, of

course, probable that continued investigations and use will indicate certain laws governing the action of these aluminates, and thus indicate the most desirable compositions for certain purposes. We will then be enabled from analyses of materials to which they are to be added, to determine the character of aluminate best suited to them and the proper amount to add. But at present we have to be content with arriving at approximate results by experiment.

Turning now to the effect produced by the addition of these aluminates to mortars made (1) from lime alone, (2) from mixtures of lime and silicious material and (3) of lime and puzzolanic materials, and (4) from natural cements, we will consider each application in the order named. This order, however, bears no relation to commercial importance, although it is true that the addition of aluminate to lime is furthest advanced, so far as actual use is concerned; aluminate plasters are now being placed on the market in the regular course of trade, where they are meeting the most gratifying reception.

1. Aluminates may be added to lime at any time prior to use. The most convenient method, however, is to incorporate them with the lime in the form of a dry hydrate, in which condition they can be handled and stored in the same manner as Portland cement, as they keep well. These "Alca" plasters require no special treatment on being mixed with sand and water at the work. In some cases the sand and hair, if to be used for plastering, are added before delivery to the consumer.

A quite extended experimental and commercial use covering a period of over two years has demonstrated that besides greatly increasing the rapidity of hardening of lime mortars, the addition of aluminates to lime increases the plasticity, and the sand-carrying, and spreading properties of the mortar, which works smoothly under the trowel and is devoid of tackiness. The mortar can be re-tempered, if desired, without apparent injury; for the process of hardening apparently differs from that of gypsum or cement, resembling more the solidification on cooling of a gelatinous substance than one produced by crystallization. That the ultimate hardness or strength, however, is the result of crystallization, is indicated by the fact that these mortars harden with time under water, and attain ultimately—when exposed to moisture—a

strength greater than when stored in dry air, which apparently deprives them of their water before the chemical reactions are completed. In practice, it will be found that these mortars, when used for wall plaster, harden sufficiently in two or three hours to allow the second coat to be applied, and in two days—under normal conditions—are sufficiently hard to allow white-coating. The aluminate-lime mortars are also serviceable for bricklaying and masonry work, and attain, as shown by the physical tests, Columns 1 and 2, Table I, very considerable strength in air at short periods, which continues to increase until at long periods it approaches that of cement.

It may be interesting in this connection to give the results obtained in the laboratories of the *Die Tonindustrie Zeitung*, Berlin, on a lime-aluminate-plaster mix, 10 parts aluminate, 90 parts hydrated lime, and 300 parts normal sand:

	Tensile Test.	Compression Test.
7 days in air	59 lbs. per sq. in.	356 lbs. per sq. in.
28 days in air	94 " " " "	700 " " " "

This is about four times the strength of lime-and-sand mortars at the same periods.

2. The hardness and strength of lime-alumina mixtures can be greatly increased when the mortar is to be exposed to moisture by the addition of finely divided silicious material or clay matter, as is shown by the tests summarized in Columns 3, 4, and 5, Table I. The silicious material in Column 3 was ashes from anthracite coal burned in the ordinary household hot-air furnace. The silicious material in Column 4 was ground Salmon brick. That in Column 5 was a silicious shale of the character common along the California coast, which, however, might be more properly classed as a puzzolanic material, since a mixture of lime and this shale, without the addition of aluminate, in time attains considerable strength. Untreated clay may be used, but the effect is greatly increased if the clay is roasted. The temperature, however, should be carried only to a point sufficient to de-hydrate the clay, for over-burning reduces its activity.

3. The strength of a mixture of natural puzzolanic material and lime mortars is greatly increased by the addition of aluminates, especially at the 7- and 28-day periods, as shown by the test results

TABLE I.—TESTS OF VARIOUS MIXTURES MADE FROM ALUMINATES AND MORTAR-MAKING MATERIALS.
All Mortars, 1 Part Cement to 3 Parts Standard Ottawa Sand. Results given are averages of 3 or 5 test pieces.

Column	1	2	3	4		5	6		7	8	9			10
Lab. No.	890	53090	1870	10080		8460	2820		19740	12540	9790			
Materials in Parts by Weight	10 Al. 2 Pl. ..... 88 Lime	10 Al. 2 Pl. ..... 88 Lime	12 Al. 29 Lime ..... 59 Clay	10 Al. 45 Lime ..... 45 Clay		10 Al. 45 Lime ..... 45 Ashes	10 Al. 45 Lime ..... 45 Trass		10 Al. 2 Pl. 17.5 Lime ..... 72.5 Slag	10 Al. 90 Slag ..... Cement	5 Al. 5 Lime 2 Pl. 88 Nat. Cem.			Aver of 36 tests; Treated Cement
Fineness { 100	N. M.	N. M.	N. M.	99.8%		N. M.	N. M.		100%	99.2%	98.3%			
Fineness { 200	N. M.	N. M.	N. M.	94.0 "		N. M.	N. M.		98.4 "	94.4 "	92.4 "			
Setting Time		Hrs. Min.	Hrs. Min.	Hrs. Min.			Hrs. Min.		Hrs. Min.	Hrs. Min.	Hrs. Min.			
Initial	N. M.	1 20	5 0	0 16		N. M.	1 30		5 30	6 13	2 20			
Final	N. M.	24 0	7 0	7 0		N. M.	5 0		8 30	9 10	3 50			
Tested Under	Tension	Tension	Tension	Tension		Tension	Tension		Tension	Tension	Ten.	Ten.	Com.	
Stored in	Air	Air	Water	Air	W.	Water	Water		Water	Water	W.	W.	W.	Water
Composition of Test Pieces	1:3	1:3	1:3	1:3	1:3	1:3	Neat	1:3	1:3	1:3	Neat	1:3	1:3	1:3
Strength in lbs. per sq. in. 24 Hours	61	33	N. M.	N.M.	N.M.	N. M.	70	58	206	N. M.	227	107	N.M.	119
7 Days	101	55	105	122	21	N. S.	200	208	436	330	337	212	1131	225
28 Days	94	80	258	172	72	28	240	305	516	401	450	330	1668	328
3 Months	125	97	342	158	158	140	310	370	597	443	453	336	2164	416
6 Months	136	N. M.	390	145	263	188	305	390	633	405	480	453	2252	475
9 Months	190	107	N. M.	160	377	275	N.M.	N.M.	N. M.	433	423	493	2741	488
1 Year	210	100	365	...	410	315	N.M.	N.M.	N. M.	472	427	450	2718	494
18 Months	....	201	....	...	...	....	...	...	....	....	...	...	...	....
2 Years	....	243	....	...	...	....	...	...	....	....	...	...	...	....

ABBREVIATIONS: Al. (Alumina); Pl. (Plaster); N. M. (Not made); Ten. (Tension); Com. (Compression); W. (Water).

TABLE II.—SHOWING AVERAGE RESULTS AT 7 AND 28-DAY PERIODS OBTAINED BY TREATING NATURAL CEMENTS WITH CALCIUM ALUMINATE.

BRAND.	DESCRIPTION OF CEMENT.	NO. OF TESTS.	SETTING TIME.				TENSILE STRENGTH, LBS. PER SQ. IN.					
			Initial.		Final.		Neat.			1 Cement: 3 Ottawa Sand.		
			Hrs.	Min.	Hrs.	Min.	24 Hrs.	7 Days.	28 Days	24 Hrs.	7 Days.	28 Days
A. Lot 1	Untreated	2	1	30	4	7	180	325	468	109	182	264
	Treated	5	2	57	5	20	277	505	597	159	256	386
A. Lot 2	Untreated	2	1	55	4	5	201	301	349	109	151	231
	Treated	4	3	15	5	15	268	395	433	204	248	379
A. Lot 3	Untreated	3	2	22	3	30	203	401	473	78	181	191
	Treated	7	3	..	5	5	283	533	636	132	243	347
A. Lot 4	Untreated	2	..	34	2	33	269	461	509	88	172	231
	Treated	4	3	29	5	23	325	527	652	135	284	380
B	Untreated	1	..	35	1	10	212	183	245	42	55	125
	Treated	1	2	..	4	5	297	425	432	125	213	290
C	Untreated	1	1	45	3	50	103	247	308	20	82	200
	Treated	2	3	10	4	50	220	319	367	106	191	276
D	Untreated	1	1	25	2	30	113	192	250	43	87	230
	Treated	7	2	10	3	20	177	267	309	94	200	340

in Column 6, Table I. The trass used in this test was from Cologne, Germany.

Column 7 refers to an artificial puzzolanic cement made from a mixture of granulated slag and lime, to which aluminate was added. This sample was made in the laboratory, and may have contained more flour than commercial cements.

Column 8 shows the effect of adding aluminate to a sample of slag cement secured in the open market. Besides increasing the rapidity of set and the strength of slag cements, the addition of aluminate increases the resistance to abrasion.

4. With the exception of lime, more work has been done, both in the laboratory and in a practical way, with natural cements than with any other material.

Column 9, Table I, shows a typical one-year test, under both tension and compression, of a natural cement, to which aluminate had been added. Column 10 shows the average of thirty-six tests of 1 : 3 mortar under tension.

Table II shows the average results obtained up to the 28-day period on a number of natural cements from different sections of the country, and of widely varying analyses.

Table III shows the analyses of a number of these natural cements, the same letters and lot numbers being used as in Table II, so they may be readily identified.

TABLE III.—ANALYSIS OF UNTREATED CEMENTS OF TABLE II.

(All values given are percentages.)

Brand.	A. Lot 1.	A. Lot 2.	A. Lot 3.	A. Lot 4.	B.	C.	D.
Silica (SiO_2)	24.90	24.80	22.90	25.20	19.44	24.12	24.00
Alumina (Al_2O_3)	5.97	5.33	6.27	6.31	10.27	9.59	8.83
Ferric Oxide (Fe_2O_3)	1.93	1.87	1.63	1.69	4.25	1.75	2.57
Lime (CaO)	58.50	57.70	58.70	59.50	37.62	52.76	51.30
Magnesia (MgO)	1.69	1.40	1.80	2.09	17.36	2.82	2.66
Sulphuric Anhydride (SO_3)	1.30	1.41	1.22	1.15	2.36	1.34	1.35
Loss on Ignition	5.40	7.00	7.30	4.20	7.28	8.16	9.44

Recently several manufacturers of natural cement have started the production of "Alca" natural cements on a commercial scale, and the practical results to date confirm those of the laboratory; and before the summer is over, it is hoped that like "Alca" plasters, these "Alca" cements will have obtained recognition and made for themselves a place among structural materials.

If so, the next decade may witness a more extended use in construction of the oldest cementing material known in the building art,—Roman cement,—which seems to be in a fair way to regain its former standing and even replace to a greater or less extent Portland cement, which has supplanted it more by reason of being better adapted to the speed demanded in modern construction than to any superiority in ultimate strength or durability.* To those who remember the time when Portland cement was regarded as a curiosity and natural cement was the main reliance of the engineer in all important construction (which reliance has been justified by a record of a hundred years' service with not a single failure on important work), the thought of the rehabilitation of natural cement may not seem so impossible —so visionary—as it may to the younger men who know only Portland cement. It is almost one hundred years since natural cement was first produced in the United States, and it would be a happy coincidence if the centennial of its first production here should witness a general revival of its use.

* Since the writing of this paper, the first 18-month test on "Alca" natural cement was made. The material consisted of a mixture of 5 parts aluminate, 2 parts plaster, and 93 parts natural cement, and this was mixed into a mortar with 3 parts by weight of standard Ottawa sand. The results were as follows:

725 lbs. per sq. in.
785 " " " "
750 " " " "

Average, 756 lbs. per sq. in.

DISCUSSION.

Mr. Lesley.

MR. ROBERT W. LESLEY (*Chairman*).—Mr. Spackman's paper certainly opens up a new and very interesting field, especially in the utilization of a great many materials that are accessible, and which hitherto have not been used because they did not produce strong mortars. I should be very glad to have this paper discussed, as it presents many points of interest.

Mr. Waldo.

MR. LEONARD WALDO.—This paper has a very unexpected bearing upon an apparently totally irrelevant subject. The question of refractories presents a very difficult situation, chiefly through the advent of the electric furnace and the high temperatures in modern metallurgical processes. The combinations of calcium and aluminum, and their oxides, of course, seem to offer most promising channels for investigation. I should like to ask Mr. Spackman as to the chemical formula of calcium aluminate, and whether it contains any water, or anything which would naturally cause it to disintegrate at high temperatures.

Mr. Spackman.

MR. HENRY S. SPACKMAN.—Calcium aluminate is made by furnacing and is an anhydrous compound. The formula seems to be unimportant. Sheppard and Rankin have shown four distinct compounds. It is very probable, though, that in cements we are dealing with a chemical mixture produced by diffusion in the presence of heat, and our tests indicate that no chemical formula is necessary to produce results as to cement. If the cement was used to line a furnace, and mixed with water, there would be water of hydration present. Whether it would dehydrate in the presence of heat, and then fuse and make a stable lining, I cannot say, as I have never made such an experiment; but it seems to me that it might, if the dehydration was not sufficiently rapid to cause the disintegration of the cement.

Mr. Chapman.

MR. C. M. CHAPMAN.—I should like to ask what the term "treatment" or "treated" means, in Table II. Does it mean simply the mechanical admixture of a certain percentage of aluminate?

MR. SPACKMAN.—It means simply a mechanical mixture obtained by adding the aluminate. The percentage is not given in Table II, but I can very readily add it. It is 10 per cent. in every instance. **Mr. Spackman.**

MR. LESLEY.—It seems to me that so far as the cement is concerned, those four Belgian cements, which all appear to be just below the specifications of Portland cement, are practically carried above the standard of Portland cement specifications of almost any country. As I understand it, there is no treatment of those at all, is there, Mr. Spackman, except in the addition of aluminate? They were not ground finer, or altered, in any way, were they? **Mr. Lesley.**

MR. SPACKMAN.—They were not altered in any way. Two samples of each lot were submitted in order to get an idea of the average production of the kiln. They were simply mixed with the aluminate. I should like to state that the addition of lime is mainly to assist in retarding the set. The addition of aluminate to a quick-setting cement makes it so quick-setting in some cases that it cannot be controlled. The addition of about 2 per cent. of lime is generally sufficient. Some cements in which the lime is in an active condition are not improved by the addition of lime. In others, which may have been harder burned, the addition of lime will improve the strength as well as the set. **Mr. Spackman.**

MR. LESLEY.—Having had a little experience with natural cements in the early days, this rather takes me back to the pastures of my youth. Natural cements in this country practically controlled the market in the seventies. Everything was done with natural cement. Along in the seventies we began to import some of the English cement, and after that the German, and we gradually saw natural cement dropping further and further backward until this great big Portland cement industry simply swept over the country, driving everything before it. **Mr. Lesley.**

Now engineers want the best, and very properly so, because their reputation is at stake in every job. Natural cement certainly gave excellent results. I doubt if any one can point to failures of natural cement; but in its desire for speed in construction the country has required a cement which will harden rapidly, and against the competition of the quick-setting Portland cements, the natural cements seemed to have seen the last of their utility.

Mr. Lesley. If these experiments can be corroborated and their truth demonstrated more generally, it would seem that we might come back to the use of natural cement for very many purposes for which it has lately been abandoned. The field is an enormous one when we consider the growing use of cement, and it is likely that the natural as well as the Portland cement will continue to find increased utilities.

Mr. Boynton. MR. C. W. BOYNTON.—I should like to ask Mr. Spackman if the character of the lime seems to have any effect.

Mr. Spackman. MR. SPACKMAN.—For plasters it works equally well with magnesia lime or high-calcium lime.

Mr. Boynton. MR. BOYNTON.—Can you give the composition of the slag used?

Mr. Spackman. MR. SPACKMAN.—I cannot off hand. The slag used in the laboratory was from the Sidney Cement Company, Sidney, New Brunswick; but as I remember, it was typical slag such as is used for work of that kind, running I should say about 26 per cent. silica, 12 per cent. iron and alumina, and 48 per cent. lime. The second sample was a commercial cement made in Ohio. I do not think we analyzed it; if so, I do not now recollect it.

Mr. Boynton. MR. BOYNTON.—Do you consider that slag of different compositions will behave differently?

Mr. Spackman. MR. SPACKMAN.—I have made altogether some twenty tests, using different slags, some in the granulated form and others in the shape of commercial slag cement. The result was about the same in each case. There is no question that the result will be affected by the quality of cement to which the aluminate is added. As a general rule the increase at the 7- and 28-day periods is from 50 to 75 per cent. The Germans contend that puzzolan cements should be made from lime paste, and not from the dry hydrate. Hydrated lime makes a friable, punky mortar, which they say is due to the fact that the hydrate of lime is not colloidal when mixed with the water, and permits very rapid evaporation of the water, so that the cement becomes dry before chemical reaction takes place; whereas, if the lime has been hydrated with an excess of water, it forms a colloid in the mortar and prevents evaporation. The presence of the aluminate has the effect of giving back to the hydrated (dry) lime the colloidal quality that the lime has when hydrated with an excess of moisture.

MR. CHAPMAN.—Inasmuch as natural cements approach the Portland cements in some cases so nearly as to pass for them, and inasmuch as the addition of aluminate increases the strength of the natural cements from 25 to 200 per cent., does any one know whether it would have as marked an effect on Portland cement, and what that effect would be? **Mr. Chapman**

MR. SPACKMAN.—I may say that we have under way a number of interesting experiments in connection with Portland cement which I think will demonstrate an equally beneficial result; but as I started out with Portland cement as the standard which I wanted to approach with other materials, I did not take up the study of the addition of the aluminates to Portland cements until a much later period. I find it is very unsafe to draw conclusions from one series of tests. The test must be repeated at least twelve to fifteen times with the same materials so as to get average results before the real effect may be safely judged; but the tests indicate that Portland cement is benefited by the addition of aluminates. It is quite possible that aluminates may act as retarders, strange as that may seem, and replace gypsum. **Mr. Spackman.**

MR. CLIFFORD RICHARDSON.—I have followed Mr. Spackman's experiments with the greatest interest. It seems to me that he has undoubtedly discovered something of value and importance, and that the future may bring out a great deal which may be of still greater interest than what he has put before us to-day. **Mr. Richardson.**

COMPARATIVE TESTS OF LIME MORTAR, BOTH IN TENSION AND COMPRESSION: HYDRATED LIME AND SAND; LUMP LIME AND SAND; CEMENT-LIME AND SAND.

By E. W. Lazell.

Lime mortar has been used for ages in building construction. The ancient builders were skilled in its use, as is evidenced by the numerous ruins of their works still in existence. The Romans especially became skillful in the use of lime mortars, and further, were familiar with the hydraulic properties imparted to lime by the addition of puzzolanic materials, such as the volcanic ash found in the vicinity of Rome. The endurance of this particular mortar is attested by the examples of Roman construction to be seen in a good state of preservation even to-day, after having been exposed to the elements for centuries. Attention is often called to the superiority of the construction work accomplished by the ancient builders as compared to that done in modern times. It must be remembered however that their skill is only judged to-day from the best examples of their work, since it is only these which have survived to the present, the greater part of their work having been destroyed by the ravages of time. In general, those buildings and monuments which have survived owe their preservation to the good quality of the materials of construction used, their actual location having been fortunately convenient to a source of good building materials, such as stone, sand and lime.

The science of the testing of the materials of construction to determine their strength, durability and fitness for the work desired is modern, and one to which this Society devotes its energies. In spite of the large use of lime mortar as a material of construction, there are but few serviceable data available regarding the quality of the different mixtures and their actual strength in ordinary use. It was with the desire to contribute some little information on this score with regard to lime mortars that this paper was prepared.

The object of this investigation was to determine the relative strength of mortars made from various limes in common use in the New York City market. The tests cover both plain lime mortars and cement-lime mortars. The limes used were such as

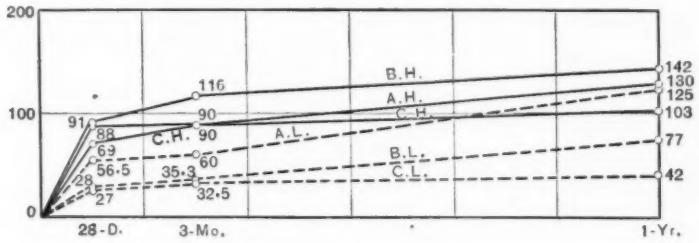


FIG. 1.—TENSION TESTS.

Proportions of Mixture.
1 Part Cementing Ingredient, 3 Parts Sand.
1 Part Lime, 3 Parts Sand.

are found in the market in two forms, that is, as lump lime and as hydrated lime. The samples employed for the tests were all procured in the New York market in bag or barrel lots, and were obtained by Professor Ira H. Woolson of Columbia University, under whose direction all tests were made.

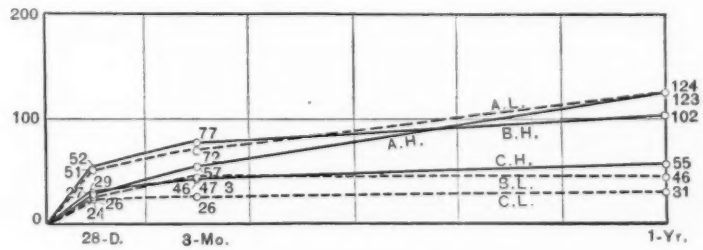


FIG. 2.—TENSION TESTS.

Proportions of Mixture.
1 Part Cementing Ingredient, 5 Parts Sand.
1 Part Lime, 5 Parts Sand

Before describing the results in full, it will be well to call attention to the difference in the processes of hardening as evidenced in cement mortars and in lime mortars. Cement mortars harden by chemically combining with water, and thereby forming the

binding material which holds the sand grains together. Lime mortars harden first by simply drying out. The lime paste, which is a tenacious and sticky substance, surrounds the sand grains, and the first hardening or setting is simply due to the loss of water by evaporation, which produces a mechanical bond. In the course of time the lime combines with the carbonic acid of the atmosphere, and thus forms a stronger bond, the amount of bonding material and the strength of the bond increasing until all of the lime present has been changed into the carbonate.

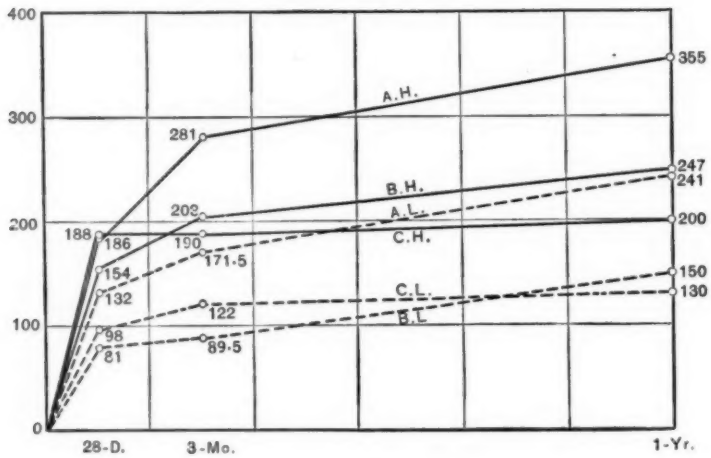


FIG. 3.—TENSION TESTS.

Proportions of Mixture.

1 Part Cementing Ingredient, 3 Parts Sand.

$\frac{50}{100}$ Cement, $\frac{50}{100}$ Lime, 3 Parts Sand.

Character of Limes Used.—A. L. (on the diagrams) was a lime made from a very pure dolomitic limestone. This lime contained about 55.2 per cent. of CaO, 38.0 per cent. of MgO, and 1.5 per cent. of impurities.

A. H. was the hydrate prepared from A. L.

B. L. was a lime made from high-calcium lime rock. This lime contained 94 per cent. of CaO, less than 1 per cent. of MgO, and about 2 per cent. of impurities.

B. H. was the hydrate prepared from B. L.

C. L. was a lime made from high-calcium lime rock. This

lime contained about 95.5 per cent. of CaO, 2.25 per cent. of MgO, and about 0.80 per cent. of impurities.

C. H. was the hydrate prepared from C. L.

It will be seen that the above limes represent three classes:

1. A pure dolomitic limestone.

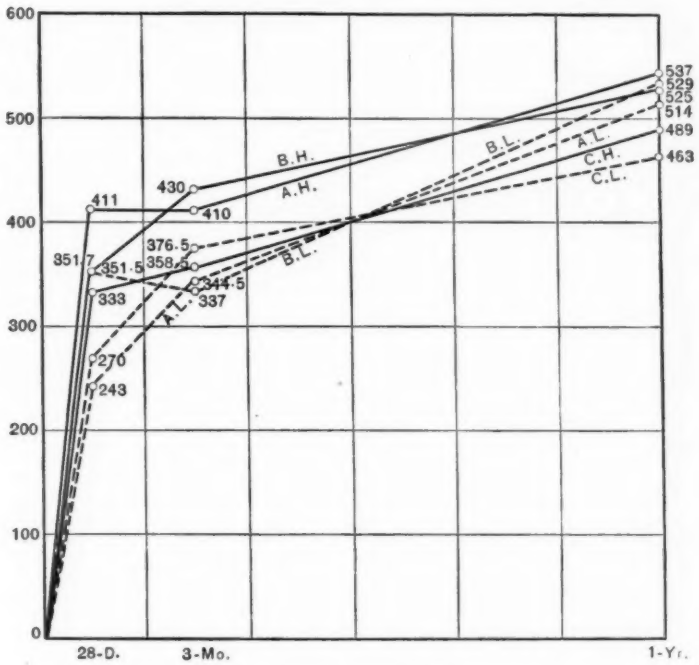


FIG. 4.—TENSION TESTS.

Proportions of Mixture.

1 Part Cementing Ingredient, 3 Parts Sand.

$\frac{85}{100}$ Cement, $\frac{15}{100}$ Lime, 3 Parts Sand.

2. A high-calcium limestone containing about 2 per cent. of impurities.

3. A high-calcium limestone containing less than 1 per cent. of impurities. The various hydrates were all made for commercial use by their respective manufacturers at the same points at which the limes used were burned.

Preparation of the Test Pieces.—In order that the test pieces might be as nearly alike as possible, they were all made by one

man. This man has had twenty years' experience in cement testing, and is considered an expert at his work.

All proportions were made by weight. Ottawa sand was

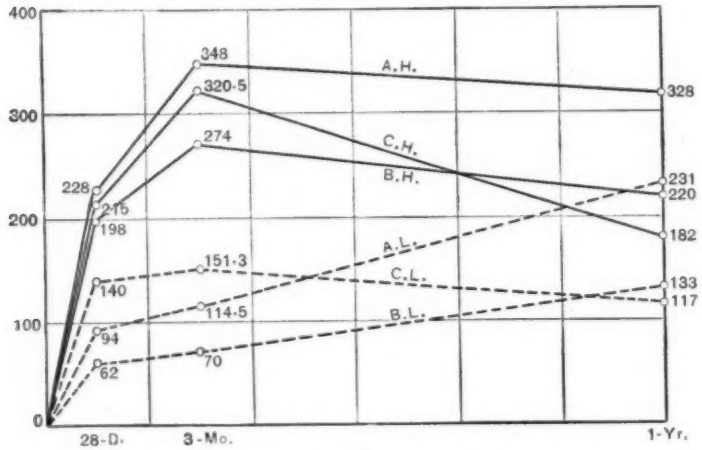


FIG. 5.—TENSION TESTS.

Proportions of Mixture.

1 Part Cementing Ingredient, 5 Parts Sand.

$\frac{65}{100}$ Cement, $\frac{35}{100}$ Lime, 5 Parts Sand.

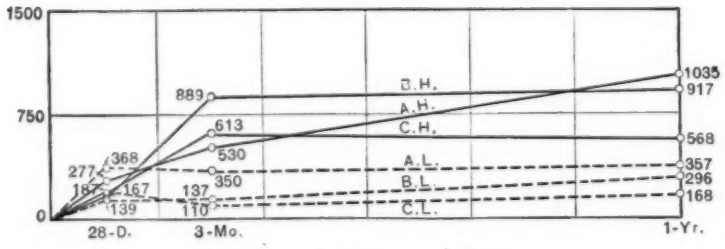


FIG. 6.—COMPRESSION TESTS.

Proportions of Mixture.

1 Part Cementing Ingredient, 3 Parts Sand.

1 Part Lime, 3 Parts Sand.

used in all test pieces. The unit weight of lime was based upon the material as received. The briquettes made from the quicklime contained one part by weight of quicklime to three parts by weight of sand, and those made from hydrated lime contained one part by weight of hydrated lime to three parts by weight

of sand. It is therefore obvious that the test pieces made from the quicklime contained a relatively higher percentage of lime than those made from the corresponding hydrated lime, since the

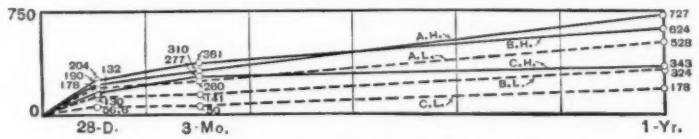


FIG. 7.—COMPRESSION TESTS.

Proportions of Mixture.
1 Part Cementing Ingredient, 5 Parts Sand.
1 Part Lime, 5 Parts Sand.

hydrated lime already contained the amount of water necessary to chemically satisfy the lime.

The lump lime and sand were slacked together with the requisite amount of water twenty-four hours before using—this

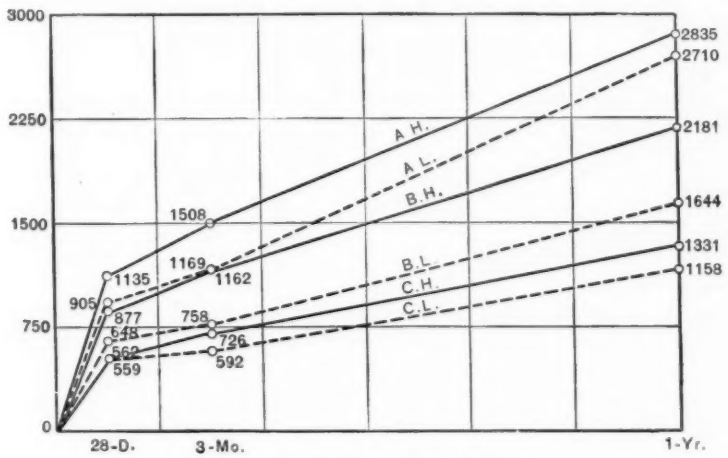


FIG. 8.—COMPRESSION TESTS.

Proportions of Mixture.
1 Part Cementing Ingredient, 3 Parts Sand.
$\frac{50}{100}$ Cement, $\frac{50}{100}$ Lime, 3 Parts Sand.

being the common practice in preparing mortar in New York. The amount of water used in slacking was determined by a number of experiments, and it varied with each class of quicklime used. There may be some doubt as to whether the results secured are as

good as would have been obtained from a longer period of ageing. They do, however, represent the strength of mortars as commonly prepared from quicklime.

Tension Tests.—Tension tests were made on standard

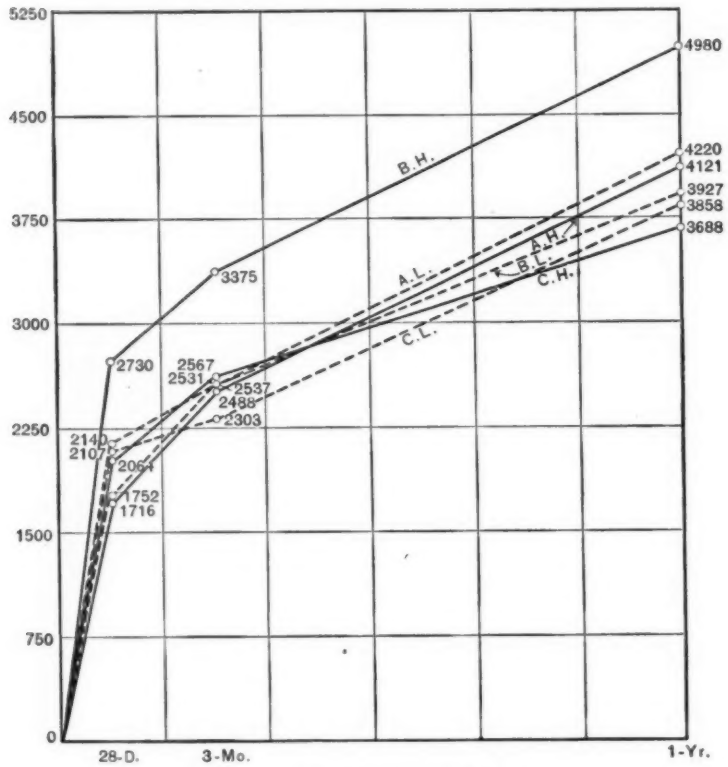


FIG. 9.—COMPRESSION TESTS.

Proportions of Mixture.
1 Part Cementing Ingredient, 3 Parts Sand.
$\frac{85}{100}$ Cement, $\frac{15}{100}$ Lime, 3 Parts Sand.

briquettes at periods of 28 days, 3 months, and 12 months. Three briquettes of each mixture were tested at each period.

Compression Tests.—Compression tests were made upon both halves of each briquette previously tested in tension. As a check upon these compression tests, a single compression test was made upon small prisms, 1 by 1 by $1\frac{1}{2}$ ins., made from each

mixture. It was found very difficult to remove these prisms from the molds in perfect condition, and as a result many of these test pieces were more or less defective. All that were really bad were, however, discarded.

It should be borne in mind that some of the compression tests on the half-briquettes were unreliable, because of the rough and rounded surfaces of the top side of the briquette where it was

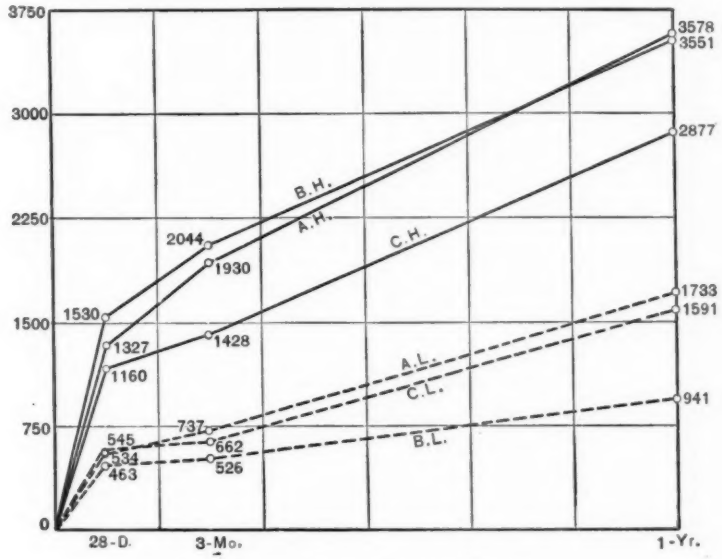


FIG. 10.—COMPRESSION TESTS.

Proportions of Mixture.
1 Part Cementing Ingredient, 5 Parts Sand.
$\frac{65}{100}$ Cement, $\frac{35}{100}$ Lime, 5 Parts Sand.

scraped off in the mold. It was not possible to face these briquettes with plaster, as is ordinarily done with compression tests on brick and concrete, because this would have spoiled the tests. The specimens were therefore well padded with blotting paper, and dependence placed upon the number of tests of each kind to average up the irregularities.

I am aware that there may be some criticism of the use of half-briquettes resulting from the tension tests for the compression tests. When the tests were first undertaken, 4-in. cubes were

used. These however hardened very slowly, because the surface exposed to the action of the atmosphere, or for the absorption of carbon dioxide, was small compared to the mass of the cube. The results obtained were very unfavorable. Small cubes and prisms were also tried, but these were difficult to remove from the molds in good condition. It therefore seemed advisable to make

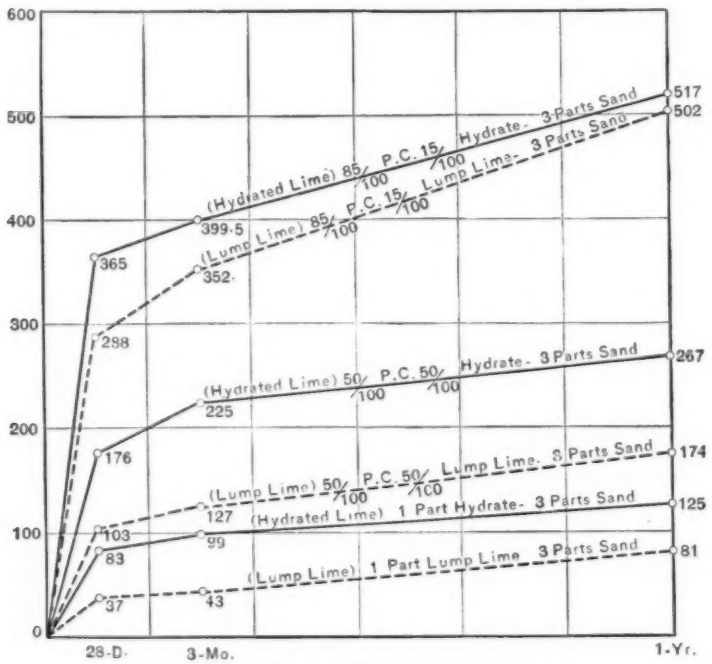


FIG. 11.—AVERAGES OF TENSION TESTS.
Comparison between Hydrates and Lump Limes.

use of the half-briquettes, thereby greatly reducing the number of test pieces required, and the cost of the investigation.

While the area of the surface in compression in the case of half-briquettes is large compared with the depth of the specimen, thus not giving the true compressive strength, it should be borne in mind that correspondingly, in actual practice, the joints in brick work are narrow and thin, resembling thin plates to which the compression is applied on the flat side.

As was to be expected, the specimens made with mixtures

rich in quicklime were more or less defective, due to cracks in them. A large number of extra specimens were made up, however, and in most cases it was possible to obtain full sets for each series. All specimens were removed from the molds as soon as sufficiently hard, and were stored in air in the basement of the laboratory. After the briquettes were removed from the molds, they were dipped in water for about two minutes every other

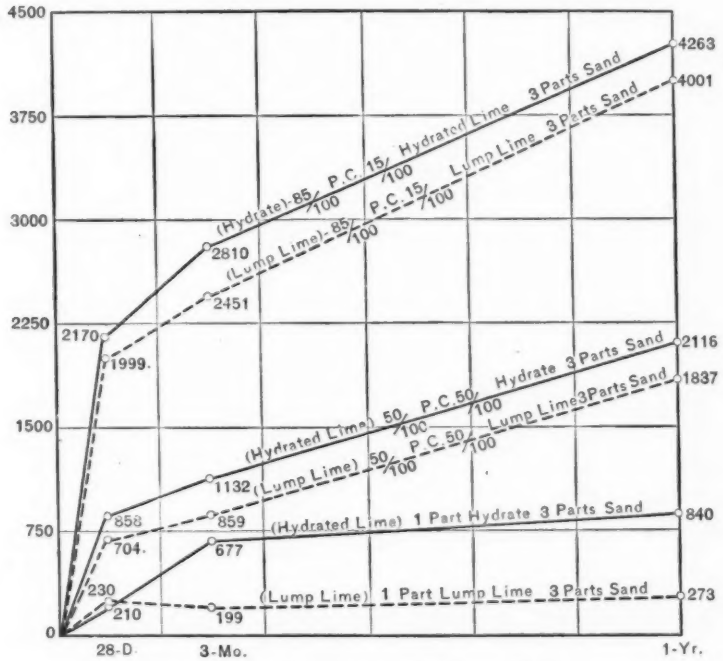


FIG. 12.—AVERAGES OF TENSION TESTS.
Comparison between Hydrates and Lump Limes.

day for two weeks, and afterwards they were dipped in water for three minutes once a week. The briquettes were thoroughly dried before being tested.

Results of the Tests.—The results obtained have been plotted as curves, the vertical height representing the strength in pounds per square inch, and the horizontal distance representing the time. In all the diagrams the solid lines represent the results obtained from the hydrate mixtures and the broken lines represent the results obtained from the quicklime mixtures.

Fig. 1 shows the results of the tension tests of briquettes made of one part of quicklime to three parts of sand, or one part of hydrated lime to three parts of sand.

Fig. 2 shows the results of the tension tests obtained from briquettes made up in the proportions of one part of quicklime to five parts of sand, or one part of hydrated lime to five parts of sand.

Figs. 3 and 4 show the results from one-to-three mixtures in which a portion of the lime has been replaced with Portland cement.

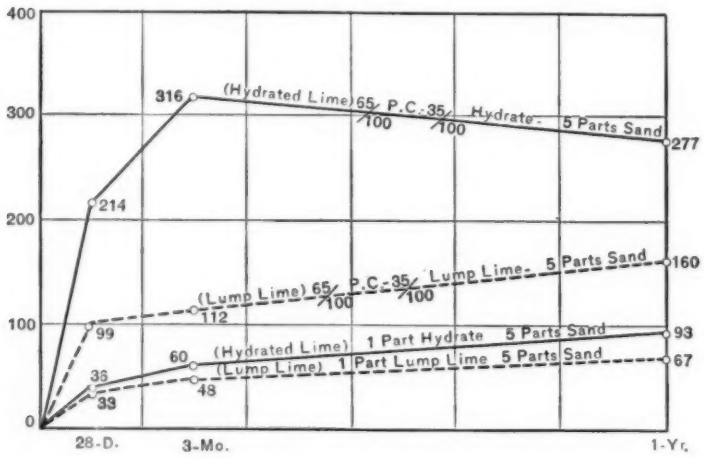


FIG. 13.—AVERAGES OF COMPRESSION TESTS.
Comparison between Hydrates and Lump Limes.

Fig. 5 shows the results from one-to-five mixtures in which a part of the lime has been replaced with Portland cement.

Fig. 6 shows the results of the compression tests on one-to-three mixtures.

Fig. 7 shows the results of the compression tests on one-to-five mixtures.

Figs. 8 and 9 show the results of the compression tests on one-to-three mixtures, in which part of the lime has been replaced with Portland cement.

Fig. 10 shows the results of the compression tests on one-to-five mixtures, in which part of the lime has been replaced with Portland cement.

The use of straight Portland-cement mortars for brick work cannot be recommended for general practice because of their lack of plasticity, which prevents the bricklayer from making a good joint and bedding the bricks thoroughly and evenly. In fact, for this very reason it is customary where Portland-cement mortar is specified, to add a gauging of lime to improve the spreading quality of the mortar. The same principle applies to stuccos or plaster containing Portland cement. To obtain the best results,

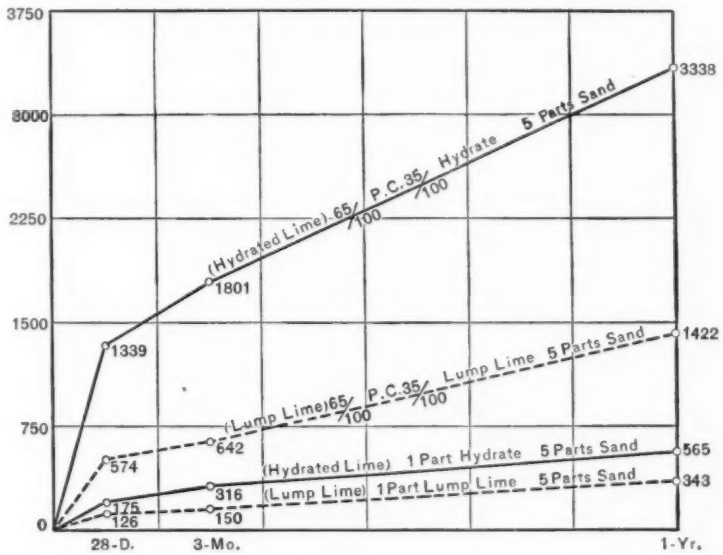


FIG. 14.—AVERAGES OF COMPRESSION TESTS.
Comparison between Hydrates and Lump Limes.

lime should be used in order that the stucco may be spread with less labor and a good clinch through the lath be assured. The results shown in the diagrams demonstrate that the lime-cement mortars possess good strength. This is made particularly obvious by the showing at the one-year period.

A study of this series of tests and of the diagrams presenting the results in visible form suggests two most interesting and significant conclusions:

1. All lime mortars, whether they contain Portland cement or not, are stronger when prepared from hydrated lime than when

prepared from quicklime. This might have been predicated, because the product of lime hydration by mechanical means in a plant properly equipped for the purpose is better than the product obtained by hydrating lime in the customary way of slacking with a hose and a hoe. In the common method of slacking, the paste or mortar must be aged for a considerable time to insure the complete hydration of all the quicklime particles. The greater strength of the mortars made from hydrated lime is well shown in Figs. 11, 12, 13 and 14. These diagrams were prepared by averaging the results obtained on similar tests of the three hydrated limes and the three quicklimes used. An advantage of the use of hydrated lime in place of lime paste in the preparation of mixed mortars lies in the greater ease of incorporation of the dry hydrated material with the other ingredients.

2. The series of tests includes five different mixtures tested both in compression and tension. Thus the set includes ten series of tests in all. In eight of the ten, the dolomitic limes are shown to have been stronger at the end of one year than the high-calcium limes. This confirms results obtained by other investigators.

It is often stated that limes made from dolomite are unsuited for use in mortars containing Portland cement, because of their high magnesium content. The results from these experiments show no deleterious effect from the magnesia, but on the contrary, indicate that the magnesia is a valuable ingredient, contributing to the strength of the mortar. It is well known that mortars made from dolomitic limes show no signs of disintegration even after years of exposure to the elements. This is proven by the long-continued use of this class of limes in such districts as Philadelphia, where practically all the lime used since the foundation of the city has been made from dolomite.

A SAND SPECIFICATION AND ITS SPECIFIC APPLICATION.

By W. A. Aiken.

During the past nine months, the writer has been engaged upon the examination of a large number of sand deposits. The sand was submitted for use on an extensive piece of railroad construction, involving some 60,000 yards of concrete masonry, where it was desired, if possible, to use local deposits adjacent to the several points of construction. The character of the deposits varied considerably, and as trouble had from time to time been previously experienced throughout the region, supposedly from inferior sands, we were engaged to pass upon the acceptability of all such material before any was allowed to be used. Complete tests were made in every instance, and the results studied as to their compliance with the general requirements of the following specification for sand, which is now submitted as a progressive step towards the elimination of the generally old-fashioned and very vague requirements covering this material. The main points of the specification were originally brought to the consideration of the Society two years ago in a paper by Mr. Henry S. Spackman and Mr. Robert W. Lesley.

A Specification for Sand.

The material shall be of such fineness that all shall pass a No. 4 sieve.

The material shall contain at least 95 per cent. of silica.

Before acceptance of the sand, the contractor shall forward to the engineer an average sample, taken from the proposed source of supply, which sample shall be subject to analysis and comparative physical tests with standard Ottawa sand.

Requirement 1.—The sand under examination, when tested with a normal Portland cement as mortar in the proportion of one part cement to three parts sand, according to standard methods, shall develop at least 75 per cent. of the strength

TABLE I.—TESTS OF SAND.

Sand Sample.	Specific Gravity.	Percentage of Voids.		Silica, per cent.	Percentage Passing Sieve.							
		Loose.	Packed.		¼ in.	No. 10.	No. 20.	No. 40.	No. 60.	No. 80.	No. 100.	No. 200.
A....	2.57	40.0	32.5	85.64	99.95	90.66	69.66	40.99	17.97	7.95	3.17	0.50
B....	2.75	37.5	32.5	83.82	98.70	94.08	73.28	26.28	5.60	2.76	1.02	0.55
C....	2.55	40.0	33.7	82.88	98.67	83.58	38.39	7.44	1.21	0.38	0.18	0.06
D....	2.57	43.5	40.0	83.64	100.00	100.00	100.00	98.71	74.78	36.21	10.71	0.86
E....	2.63	38.5	31.0	82.98	98.00	91.98	60.14	16.68	2.46	0.66	0.34	0.20
F....	2.44	35.0	32.5	85.42	95.16	83.87	60.28	30.04	8.87	3.26	1.41	0.34
G....	2.40	40.0	32.5	82.30	98.32	90.12	54.12	11.52	1.52	0.38	0.14	0.06
H....	2.58	37.5	30.0	88.40	88.06	80.46	69.66	41.06	24.06	13.94	6.54	2.12
I....	2.59	36.8	33.0	81.30	99.30	95.30	80.70	51.70	19.30	7.30	4.10	0.68
K....	2.61	40.0	32.5	87.20	97.28	82.28	68.08	48.08	21.48	9.88	4.68	1.08
L....	2.59	32.5	29.0	89.18	92.92	84.92	62.52	39.92	19.92	11.92	6.32	1.32
M....	2.55	35.0	30.0	78.10	87.68	69.68	43.68	13.68	2.08	0.48	0.22	0.06
N....	2.62	37.5	32.0	97.06	99.22	99.04	89.04	50.64	20.84	10.24	3.84	1.86
O....	2.56	35.0	30.0	95.08	87.98	85.98	83.78	78.18	55.02	33.89	26.38	17.16
P....	2.53	40.0	35.0	89.18	99.80	96.80	72.60	31.80	9.40	3.60	1.72	0.16
Q....	2.62	40.0	34.0	94.70	87.02	66.22	34.62	6.82	0.82	0.28	0.20	0.10
R....	2.52	35.0	30.0	83.02	91.74	69.74	39.34	6.54	1.74	1.20	1.00	0.64
S....	2.59	45.0	37.5	85.54	97.38	93.98	83.78	50.98	14.58	5.98	1.98	0.28
T....	2.56	40.0	35.0	93.24	97.20	92.20	75.60	33.20	10.80	5.60	2.80	0.80
U....	2.50	38.5	33.5	90.76	99.54	98.86	86.26	26.66	2.86	0.42	0.16	0.06
V....	2.62	42.0	35.0	87.74	98.18	96.18	67.58	15.58	4.78	1.98	0.78	0.22
W....	2.50	40.0	32.0	85.06	93.02	78.62	53.42	18.82	4.42	1.62	0.76	0.38
X....	2.57	37.5	32.5	75.04	91.36	82.76	66.76	39.16	17.16	8.36	3.56	0 76
Y....	2.55	37.5	34.5	81.66	89.54	82.74	63.74	26.34	7.94	2.74	0.94	0.22
Z....	2.67	50.0	40.0	84.80	100.00	100.00	98.40	88.80	23.20	10.00	4.40	1.00

developed in similarly proportioned mortar of the same cement and standard Ottawa sand. But in no case shall such sample mortar under investigation, in a 1 : 3-mixture briquette, when tested in tension, fail at less than 150 lbs. at 7 days or 200 lbs. at 28 days.

Requirement 2.—The sand under examination, when tested as mortar in the proportion of one part cement to three parts sand, gauged by hand with 50 per cent. excess of the normal quantity of water, shall develop at least 50 per cent. of its strength at identical periods, when normally gauged. But in no case shall such sample mortar under investigation, in a 1 : 3-mixture briquette, 50 per cent. excess gauge, when tested in tension, fail at less than 100 lbs. at 7 days or 150 lbs. at 28 days.

Requirement 3.—After complete tests have been made to determine the character of the representative sample, each carload of sand to be used shall be subjected to the above-described analysis and tests, and shall develop at 7 days, under similar methods of testing and gauging, at least 80 per cent. of the strength of the original sand sample shown by the preliminary tests under which the sand may have been accepted.

Table I shows the results of the detailed sieve tests, void determinations, specific gravity determinations, and silica contents of each of the twenty-five samples under investigation.

Before it was decided what brands of cement would be used in the work, the samples from the first four sand deposits were originally tested with three standard brands of cement; later another was added, and this was principally used on the actual construction. The specifications of the chief engineer of the work required the use of crushed quartz in all laboratory tests, instead of the usual Ottawa sand.

Table II gives the results of tests of the above-mentioned four brands of cements under normal methods.

Cements 2 and 4 were finally determined upon as of satisfactory quality, but while some considerable quantity of the former was used in the earlier stages of the work, fully ninety per cent. of the concrete has been made up with Cement 4. The results of tests of the first four samples of sand, 1:3 mortar, before Cement 4 came into use, are given in Table III.

TABLE II.—TESTS OF CEMENT; STRENGTH IN POUNDS.

Cement.	Neat.			1:3 Crushed Quartz Mortar.					
	24 hours	7 days.	28 days.	Water, Normal Gauge.		Water, 50 per cent. Excess Gauge. Hand-mixed.		Water, 50 per cent. Excess Gauge. Ball Mill Treatment. Machine-mixed.	
				7 days.	28 days.	7 days.	28 days.	7 days.	28 days.
1.....	333	608	732	231	364	171	279	....	....
2.....	362	685	714	205	257	196	296	217	312
3.....	177	704	897	235	361	162	251	....	....
4.....	417	798	817	249	400	155	301	203	293

Sands B and D were rejected for failure to comply with the physical test condition of the above specification. It may be said here that no insistence was made on the silica requirement, since the sands were not furnished under our suggested specifications; but this requirement has guided us in our investigations, and the silica clause is offered as our idea of an essential. The tables presented herewith certainly demonstrate its value, which is much greater in our opinion than any granulometric requirement. Naturally, of two sands showing practically the same silica content, one well graded and one poorly so, the former will give better tests results; but the influence of the silica content is very marked

TABLE III.—TESTS OF MORTAR; STRENGTH IN POUNDS.
All Sand Tested as 1 : 3 Mortar.

Sand.	Cement.	Water, Normal Gauge.		Water, 50 per cent. Excess Gauge. Hand-mixed.		Water, 50 per cent. Excess Gauge. Ball Mill Treatment. Machine-mixed.	
		7 days.	28 days.	7 days.	28 days.	7 days.	28 days.
A..	1	167	337	95	189	142	300
	2	233	346	128	242	142	349
	3	206	346	113	230	...	...
B..	1	146	245	75	163	...	...
	2	174	263	90	154	83	144
	3	111	225	61	143	...	...
C..	1	269	395	115	193	...	...
	2	329	373	139	242	192	280
	3	255	365	135	230	...	...
D..	1	76	157	22	92	...	...
	2	90	195	36	102	79	165
	3	129	199	101	192	210	216

TABLE IV.—TESTS OF SAND WITH CEMENT; STRENGTH IN POUNDS.

Sand	Silica, per cent.	Percentage passing No. 100 Sieve.	Percentage between Nos. 40–60 Sieves.	Cement 2.						Cement 4					
				Normal.		50 per cent. Excess.		50 per cent. Excess, Ball Mill Treatment.		Normal.		50 per cent. Excess.		50 per cent. Excess, Ball Mill Treatment.	
				7 days	28 days	7 days	28 days	7 days	28 days	7 days	28 days	7 days	28 days	7 days	28 days
N	97.06	3.84	29.80	331	435	141	307	189	351	337	447	138	265	221	367
O	95.08	26.38	23.16	315	478	116	232	245	370	307	451	149	254	229	360
Q	94.70	0.20	6.00	329	451	109	204	172	315	337	451	151	209	205	315
T	93.24	2.80	22.40	356	501	150	279	168	250	379	525	169	263	184	313
U†	90.76	0.16	23.86	160	256	85*	192*	152*	236	201	317	78*	166*	130*	245
L	89.18	6.32	20.00	263	418	91	193	158	276	301	396	128	245	187	316
P	89.18	1.72	22.40	201	315	104	245	128	253	245	376	147	268	176	270
H	88.40	6.64	17.00	222	365	113	232	110	233	290	372	140	280	178	293
V	87.74	0.78	10.80	260	419	134	259	128	250	259	414	108	213	155	252
K	87.20	4.86	26.60	263	376	131	269	181	304	248	375	135	292	192	307
A	85.64	3.17	23.02	233	346	128	242	142	249						
S†	85.54	1.98	36.40	218	318	123*	201*	131*	222*	180*	371	92*	174*	122*	227
F	85.42	1.41	21.67	182	288	117	221	145	266	234	313	120	234	146	261
W†	85.06	0.76	14.40	266	413	101*	201*	136*	265	255	414	73*	195*	131*	268
Z†	84.80	4.40	65.60	133*	273	50*	148*	47*	165*	132	268	72*	177*	77*	173*
B†	83.82	1.02	20.68	174	263	90*	154*	83*	144*						
D†	83.64	10.71	23.23	90*	195	36*	102*	79*	165*	129	199	101*	192*	210	216*
R	83.02	1.00	4.80	276	387	112	204	130	222	323	434	124	224	183	269
E	82.98	0.34	14.22	260	296	84	216	103	229	220	290	143	236	155	251
C	82.88	0.18	6.23	329	373	139	242	192	280						
G	82.30	0.14	10.00	222	332	112	235	172	299	245	360	151	283	214	299
Y	81.66	0.94	18.40	255	374	147	278	127	275	317	400	194	316	220	326
I	81.30	4.10	23.40	191	300	125	238	149	275	210	320	120	218	150	259
M	78.10	0.22	11.60	250	354	114	217	187	254	276	357	126	235	188	279
X	75.04	3.56	22.00	241	415	128	224	133	271	218	367	108	220	134	232
Crushed quartz				205	257	196	296	217	311	249	400	155	301	203	293
75% of crushed quartz strength				154	193	147	222	163	233	187	300	116	226	152	220

* Failed by Requirement 1. † Rejected.

on a poorly graded material, and of two sands of the same granulometric analysis, one of high silica content and the other showing much less, the test results with the former will be infinitely the better.

TABLE V.—WITH 50 PER CENT. EXCESS GAUGING, TO SHOW 50 PER CENT. OF THEIR STRENGTH WHEN NORMALLY GAUGED.

ACCEPTED SANDS.

Sand.	Cement 2.						Cement 4.					
	50 per cent. of Normal.		Excess Gauge, Hand-mixed.		Excess Gauge, Machine-mixed.		50 per cent. of Normal.		Excess Gauge, Hand-mixed.		Excess Gauge, Machine-mixed.	
	7 days	28 days	7 days	28 days	7 days	28 days	7 days	28 days	7 days	28 days	7 days	28 days
N	165	217	141	307	189	351	168	223	138	265	221	367
O	157	239	116	232	245	370	153	255	149	254	229	360
Q	164	225	109	204	172	315	168	255	151	209	205	315
T	188	255	150	279	168	250	190	262	169	263	184	313
L	132	209	91	193	158	276	150	198	128	245	187	316
P	100	157	104	245	128	253	122	180	147	268	176	270
H	111	182	113	232	110	233	143	186	140	280	178	293
V	130	209	134	259	128	250	130	207	108	213	155	252
K	131	186	131	269	181	304	124	188	135	292	192	307
A	116	178	128	242	142	249	....	....	....	....	....	....
F	91	144	117	221	145	266	117	157	120	234	146	261
R	138	193	112	204	130	222	161	217	124	224	183	269
E	130	148	84	216	103	239	110	145	143	236	155	251
[illegible]	165	186	139	242	192	280	....	....	....	....	....	....
G	111	166	112	235	172	299	122	180	151	283	214	299
Y	128	187	147	278	127	275	158	200	194	316	220	326
I	95	150	125	238	149	275	105	160	120	218	150	250
M	125	177	114	217	187	254	138	178	126	235	188	279
X	120	207	128	224	133	271	109	188	108	220	134	232

REJECTED SANDS.

U	84	128	85	192	152	236	100	159	78	166	130	245
S	109	159	123	201	131	222	90	156	92	174	122	227
W	133	206	101	201	136	265	128	207	73	195	131	268
Z	67	136	50	148	47	165	66	134	72	177	77	173
B	87	132	90	154	83	144	....	....	....	....	....	....
D	45	98	36	102	79	165	65	100	101	192	210	216

	Cement. 2	4
ACCEPTED SANDS.		
Percentage of average increased strength of machine-mixed over hand-mixed excess-gauged mortars at 7 days	20.66	32.58
Percentage of average increased strength of machine-mixed over hand-mixed excess-gauged mortars at 28 days	15.32	16.78
REJECTED SANDS.		
Percentage of average increased strength of machine-mixed over hand-mixed excess-gauged mortars at 7 days	29.48	61.06
Percentage of average increased strength of machine-mixed over hand-mixed excess-gauged mortars at 28 days	19.94	24.89

In Table IV, the twenty-five samples of sand are arranged in the order of their silica content. This table shows test results with Cements 2 and 4, which have been used on the work, under the two specification conditions of normal gauging and 50 per cent. excess gauging, standard hand-mixed, and a third set of tests giving results of mechanical mixing of the excess gauge mortar.

Table V shows test results of the accepted and the rejected sands, with Cements 2 and 4, under the two specification requirements as to strength values of normally gauged and excess gauged mortars in comparison with crushed quartz mortar.

TABLE VI.—SUMMARY OF AVERAGE TEST RESULTS OF ACCEPTED SANDS OF VARIOUS SILICA CONTENT.

CEMENT 2.

Silica Content.	Normal Gauging.		50 per cent. Excess Gauging.		50 per cent. Excess in Ball Mill.		Per cent. increase in strength of machine-mixed over hand-mixed mortars.	
	7 days.	28 days.	7 days.	28 days.	7 days.	28 days.	7 days.	28 days.
Less than 80 per cent.	245	380	121	220	160	262	32.2	19.1
From 80 to 85 " "	255	327	120	236	145	265	20.8	12.3
" 85 to 90 " "	232	361	119	237	142	261	19.3	10.1
Over 90 " "	333	468	129	255	193	321	49.6	25.8

CEMENT 4.

Less than 80 per cent.	247	362	117	227	161	255	20.5	12.3
From 80 to 85 " "	263	361	144	255	184	281	27.7	10.2
" 85 to 90 " "	263	374	130	255	172	283	33.1	11.0
Over 90 " "	340	468	152	248	210	338	38.1	36.3

Of the six sands rejected, three showed silica contents between 80 and 85 per cent., two between 85 and 90 per cent., and one over 90 per cent. Of the first three, one showed over 10 per cent. material passing the No. 100 sieve, one showed over 70 per cent. material between the Nos. 40 and 60 sieves, and one showed normal granulometric analysis. Of the two between 85 and 90 per cent. silica, one showed nearly 40 per cent. material between the Nos. 40 and 60 sieves, and the other showed normal granulometric analysis. The last sand showed nothing abnormal under granulometric analysis.

The marked failure of Sands Z and D was undoubtedly due

to poor granulometric character of the material; in the first instance the large quantity of medium-size material, and in the second the large quantity of very fine material, caused the poor results. The effect of an excess of medium-size material is shown in the case of Sand S. Undoubtedly the fair showing of Sand U is due to its higher silica content.

Table VI gives a summary of the test results of accepted sands. These sands have been divided into four classes, according to silica content, as follows:

Silica Content.	Sand.
Less than 80 per cent.	M and X.
From 80 to 85 " "	C, E, G, I, R, and Y.
" 85 " 90 " "	A, F, H, K, L, P, and V.
Over 90 " "	N, O, Q, and T.

The test results for each class were then averaged, and tabulated as shown in Table VI. This table emphasizes the value of the silica requirement in a sand specification.

DISCUSSION.

Mr. Schuyler.

MR. MONT SCHUYLER.—An examination of the local sands of St. Louis undertaken by the City Laboratory indicated that the main cause of variation of the different samples was due to the grading of the particles. In the specifications written for aggregate to be used in concrete for sewers and viaducts which are at present under contract, the requirements for sand limited the percentages passing and retained on various sieves and demanded a material of silicious origin and free from all foreign substances whatsoever. Although I believe that Mr. Aiken's method is the one more generally applicable, the work cited above indicated that under our local conditions the restrictions embodied in the contract were the only ones necessary. They are certainly the quickest.

Mr. Aiken.

MR. W. A. AIKEN.—I want to add that we found from tests of twenty-five sands, that if you take two sands which are approximately of the same grading and acceptable under those conditions, one being of high silica and the other of low silica content, you will in every instance get results from 100 to 150 per cent. better with the high-silica sand. If you take two sands, one of which has a high silica content but is very poorly graded, and the other is of low silica content but well graded, you will find that the sand having the high silica content, even though poorly graded, will give much better results than the other. That is our experience with twenty-five grades of sand.

Mr. Schuyler.

MR. SCHUYLER.—The sands met with in St. Louis are of such restricted origin that the silica content does not differ materially.

Mr. Lesley.

MR. ROBERT W. LESLEY (*Chairman*).—I think it is gratifying that this question of standard specifications for sand was brought out here two years ago after a discussion of a paper presented before the Society covering very voluminous investigations of the subject. In the original code of the New York Code Commission, a specification for sand was arrived at by fixing a standard for a 1:3 mortar, which standard was to be determined

Mr. Lesley. by a comparison of the cement in use mixed with a standard sand, and the same cement mixed with the sand that it was proposed to use. A briquette mixed with the latter sand was required to develop 70 per cent. of the strength of a briquette made with the same Portland cement and the standard sand recommended by the Committee of the American Society of Civil Engineers.

In the report of the Joint Committee on Concrete and Reinforced Concrete a similar method of determining the value of sand was arrived at. I think we are progressing in the right direction. Sand certainly is an essential in the making of concrete mortar. Up to this time cement has been the goat, and has borne most of the brunt of the day whenever criticisms were made upon mortar.

THE EFFECT OF SODIUM SILICATE MIXED WITH OR APPLIED TO CONCRETE.

By Albert Moyer.

The easy abrasion, or what is commonly called "dusting," of cement-concrete floors in office buildings, has called to my attention the need of a material which could be readily and economically applied, resulting in the hardening of the concrete itself, and not producing a veneer to be soon worn off under foot or other traffic. Nearly all of the so-called floor finishes which are designed to protect the floor from dusting prove to be merely oil paints, some of them simply Portland cement ground up in varnish or linseed oil with some coloring matter and possibly some other harmless materials which would enable the inventor to obtain a patent. There did not seem to be any material on the market which would sink into the pores and itself harden, so as to form an actual wearing surface and not a veneer, with the possible exception of a chemical formula often used in France and Germany to protect plaster and to prepare it for mural decoration. This material is hydrofluosilicide of magnesium and zinc, $MgSiFl_6 \cdot ZnSiFl_6 \cdot 12H_2O$. The objection to its use for the protection of concrete floors or the hardening of concrete surfaces for any purpose whatever, is entirely from the standpoint of economy, the treatment costing from 8 to 10 cents per square foot.

I therefore started some experiments with sodium silicate, both in powdered form and in the form of waterglass. I found that the powdered sodium silicate which can be obtained commercially contained impurities which did not render it readily soluble in water. The sodium silicate in the form of waterglass of about 40° Baumé can be readily mixed with water. The object is to thin the sodium silicate down until it penetrates as deeply as possible into the pores of the concrete, making several applications until the pores are all filled and the sodium silicate flush with the surface. That which remains on the surface, being soluble, is readily washed off with water and that which remains in the pores, having come in contact with the salts, lime, and

other alkalies, hardens into what we may be pleased to term "mineral glue." From experiments extending over several months I found that we had obtained the results we had been striving for.

This suggested various other uses all of which had for their object the hardening and waterproofing of the surface of concrete: such as the protection of arrises of cast stone; waterproofing hollow concrete blocks; hardening, waterproofing, and protecting interior surfaces of cisterns; protecting buttermilk vats against the action of lactic acid; the protection of porous concrete surfaces against the action of oils; preventing efflorescence or the seeping out of soluble salts from Portland-cement mortar, concrete or stone; and the possible prevention of hair cracks and crazing. It is also entirely within the range of possibility that such treatment of interior and exterior surfaces of concrete may be of valuable assistance in solving the drain tile, alkali, and sea water problems. After it has been made and set hard for two or three weeks, and has then dried out so as to permit the introduction of sodium silicate in thin solution into the pores of the concrete, the drain tile may be immersed in a bath of sodium silicate, composed of 1 part waterglass, 40° Baumé, and 3 parts water. The immersion should be for a sufficient length of time to allow the tile to absorb the maximum quantity. It should then be removed from the bath and allowed to dry. Thus the sodium silicate coming in contact with the lime and other alkalies present in the concrete would form a mineral glue which is insoluble and very hard.

I believe I have suggested a sufficient number of uses to illustrate the possibilities of sodium silicate as applied to concrete.

The action of sodium silicate when applied to dry concrete is vastly different from its action when mixed with the cement while the concrete is being gauged. Through the courtesy of Mr. S. Warren Hartwell, Mr. W. R. Dunn, and with some opinions, advice and suggestions from Dr. Allerton S. Cushman, we carried on some experiments with cement and sand briquettes which were mixed with a thin solution of sodium silicate and water. These were compared with normal briquettes treated in the usual way, and with normal briquettes afterward immersed in water containing 10 per cent. of sodium silicate.

A series of briquettes was made of 1 part Portland cement

and 3 parts Ottawa sand, mixed with the usual quantity of water containing 10 per cent. of sodium silicate. The results show a falling off in strength compared with briquettes made from the same sample of cement, mixed with the usual quantity of water containing no sodium silicate, and immersed in water in the usual way. This falling off was noticed in both the 7- and 28-day periods.

Briquettes of 1 part cement and 3 parts Ottawa sand, mixed with the usual percentage of water containing no sodium silicate, after 24 hours were immersed in water containing 10 per cent. of sodium silicate, with the result that the strength was increased as compared with that of the same sample of cement treated in the usual way.

Reducing the results to figures, I give in Table I the average results of a full set of experiments:

TABLE I.—STRENGTH OF MORTARS CONSISTING OF 1 PART PORTLAND CEMENT AND 3 PARTS OTTAWA SAND, SHOWING THE EFFECT OF SODIUM SILICATE.

Method of Treatment.	Strength, lbs. per sq. in.	
	7 days.	28 days.
Mixed in the usual way and immersed in water.	285	347
Mixed with water containing 10 per cent. of sodium silicate and immersed in water.....	117	203
Mixed with water containing no sodium silicate, and after 24 hours immersed in water containing 10 per cent. of sodium silicate...	360	497

No neat cement tests were made for the reason that the comparisons we wished to obtain were those which would tend to show that the introduction of sodium silicate into concrete after final set would strengthen the concrete.

I also made up some briquettes of 1 part hydrated lime and 3 parts standard sand and water; also briquettes of 1 part hydrated lime and 2 parts building sand, mixed with a solution of 1 part waterglass and 2 parts water. The time of initial set was a half hour; of final set, one hour. As soon as they were dry, the briquettes were immersed in a solution of sodium silicate, 1 part waterglass, 40° Baumé, and 3 parts water. After absorbing the maximum amount of this solution, they were allowed to dry

out. These lime briquettes became hard but showed very little strength in tension; when immersed in water for several days, no disintegration took place. The object of this test was to ascertain the solubility of lime briquettes so treated.

In explanation of these properties, it is assumed that the sodium silicate coming in contact with the lime or other alkalies and alkaline earth salts, gives a reaction which causes a deposit of silicic acid. This forms an insoluble gelatinous silica and hardens into and acts as a mineral glue.

Sodium silicate mixed with the cement while the mortar is being gauged quickens the time of set, an arbitrary period determined by the stiffening of the mortar to such a degree that it will bear a wire or needle under a certain pressure. On finally hardening, however, the mortar never attains as great strength as normal, slow-setting mortar. I made a mixture of 1 part of waterglass to 3 parts of limewater—that is, water containing all the lime which it would take up in solution. On standing for a few minutes it became a jelly. I then mixed up a solution of sodium silicate and ordinary water and mixed with it neat cement to a wet consistency, probably 30 per cent. water. Within a few minutes this mass had become a stiff jelly. This jelly is very quickly formed, thus quickening the time of set, which in reality is merely a period of definite stiffness and has little or no relation to the time of maximum hardening. This jelly having been formed before the cement had time to harden, interfered with the process and weakness resulted, which is shown by the tests.

I would suggest that those interested in this subject experiment by using a retarder, such as a 10-per cent. solution of sodium hydrate caustic or a similar solution of magnesium sulphate. If the formation of the gelatinous silica is retarded until the cement has had an opportunity to set, it is possible that the strength of laboratory specimens will be increased. We might thus obtain some information as to the effect of sodium silicate on concrete if experiments are made extending over long periods of time. A set of specimens in the form of briquettes and cubes for tensile and crushing strength might be made and stored in water, and broken in regular periods of time up to two years. As far as I know this has not been done and might possibly lead to some interesting data on this subject.

Concrete is strengthened and hardened when sodium silicate in solution is applied to the surface. The concrete has hardened normally and that which is porous will allow the introduction of sodium silicate to some little depth in the pores, the depth depending upon the porosity of the concrete. The action of forming into a jelly thus takes place without interfering with the process of hardening, and this gelatinous substance forms an insoluble mineral glue.

Without experimental proof, and based upon the theory of maximum density, it is my opinion that this treatment will act as waterproofing and prevent the action of salt, alkaline, or sulphurous water on the surface. This is a subject which requires quite a number of laboratory experiments, which should be followed up by field experiments. Should these demonstrate by long time results that there is no further action of water on surfaces so treated, and that the sodium silicate remains in the form of an insoluble mineral glue, many very serious problems will have been solved, such as the action of alkalies or sulphurous soil on drain tile and other concrete products, the action of sea water on concrete, the waterproofing of tanks, the protection of tanks against certain acids and oils, and the dusting of concrete floors.

This treatment is also decidely economical. Sodium silicate in the form of waterglass is very cheap, costing less than one cent per lb., and a pound thinned down with water to the proper consistency to enter the pores of the concrete will cover quite an area. I treated the floors of the office in which I am located, covering some 1,400 sq. ft., at a cost of $0.003 (three mills) per sq. ft., which includes all labor and material.

I have taken the precaution to apply for a patent, as I find that none has been issued covering the use of sodium silicate for these purposes. The application was made to prevent others from obtaining the patent, and thus to protect the engineer and user of Portland cement by allowing the use of sodium silicate without fear that anyone is infringing on a patent. I hereby give notice that if the patent is obtained I shall donate it to the concrete industry.

DISCUSSION.

Mr. Cushman.

MR. A. S. CUSHMAN.—Our laboratory has been investigating the effect of various substances on the setting of Portland cement, and I have conducted a number of experiments with the use of sodium silicate. That the first hardening of Portland cement is due to the formation of colloids will probably be accepted. That the final hardening of Portland cement is largely due to the growth of certain more or less obscure crystalline bodies it is perhaps safe to say; but I am now speaking of that marvelous action that takes place when Portland cement is tempered with the right amount of water and in two hours has assumed a more or less rock-like hardness. The microscope up to that time certainly shows no crystalline characteristics in the mass that would account for the initial set; therefore, we must adopt the colloid explanation: the hardening is due to the formation of mineral glues. Sodium silicate probably precipitates an additional amount of colloidal material in the mass. It has been shown that the amount of water present has a great deal to do with the hardening of Portland cement. This is of course well known, but perhaps it is not so well known that if the amount of water present is carefully controlled, the hardening action will go on more rapidly and to a higher maximum. For instance, if at the time when a neat cement briquette is ready to attain its initial set, it then is immediately immersed in kerosene oil, it will be found that the hardening reactions go on there more rapidly than if the briquette is immediately transferred to water and allowed to soak. The explanation of this, as I find it, is that the Portland cement has helped itself to enough water to produce that peculiar condition which leads to the initial set. If the definite quantity of water can be held so that the reaction can proceed along its own lines, the maximum hardening effect will be attained. If the briquette is allowed to harden in the air it does not get enough water, owing to evaporation. If immersed in water we have the other extreme; too much water is present. In either case we do not get the ultimate effect that would be produced if the

briquette is kept under conditions in which just the right quantity of water is present; by immersion in oil this result is to some extent accomplished. Mr. Cushman.

Mr. Moyer has referred to the well-known fact that when a solution of sodium silicate is added to a solution of calcium hydroxide a gelatinous precipitate comes down. This precipitate is not of a definite chemical composition, but varies with the equilibrium of the reaction. If a strong solution of sodium silicate is added to a weak solution of limewater, a different precipitate results than if a weak solution of sodium silicate is added to a strong solution of limewater. The precipitate is therefore indeterminate; it may contain an excess of either lime or silica. If produced under certain conditions it may appear in the form of a jelly. Under other conditions it may assume the form of a crystalloid mass. Again, it may present under the microscope an appearance between a colloid and a crystalloid form, an intermediate state analogous to the condition assumed by certain substances when they are in the act of changing from the gaseous to the liquid phase. That is to say, between the gaseous and the liquid phase there is an indeterminate phase in which we may say that the material possesses to some extent the characteristics of a gas, and to some extent the characteristics of a liquid. And thus in the case of these precipitates, dependent upon the way they are made and the rapidity with which they are formed, we may either get crystalloids, or colloids, or an indeterminate material that partakes somewhat of the nature of a crystalloid and somewhat of the nature of a colloid. It is characteristic of all colloids to hold water as long as they are in an active colloidal condition. If a collodial precipitate is dried to a certain specific point, it will re-absorb water again. In other words, as far as water-holding power is concerned, there is a specific equilibrium between such precipitates and the surrounding atmosphere or environment. The colloidal condition can be destroyed by heat, but it takes a critical point to destroy it, and heating below that critical point will only to some extent damage it. Now if we imagine the precipitation of a colloid among the particles of Portland cement, we will see at once that there is established a condition favoring the indrawing of water. There is a struggle going on, all possible constituent compounds which tend to form seeking to satisfy

Mr. Cushman. themselves with water. Now if we add sodium silicate to Portland cement, it is possible that we are producing an action similar to that produced by immersing a fresh briquette in kerosene oil. Colloids are formed that have an affinity for water; at the same time the particles of Portland cement by decomposition of their surfaces produce another colloidal substance which has the peculiar property of welding the cement particles together and thus making a rock-like mass. Now if there is any colloidal substance present that has an affinity for water and takes part of it up, it may have the effect of absorbing any surplus of water which would tend to hold back the reaction.

It is true, as Mr. Moyer says, that under certain specific conditions the addition of sodium silicate to Portland cement will produce better results than can be got without it; but I would point out that we have learned through our experience in working with it in the laboratory, that it is possible to weaken Portland-cement test pieces with sodium silicate. It is certainly not a thing to depend upon in general use. That is, if it is not used at the right strength and under just the right conditions, a decided weakening of the test pieces will result, and in some cases complete failure.

Mr. Abraham. MR. HERBERT ABRAHAM.—I should like to ask Mr. Moyer one or two questions about this interesting subject; one is whether the age of the surface has any effect on the penetration of the sodium silicate solution; and another, whether he has determined the effect of a lengthy exposure on the surface thus treated.

Mr. Moyer. MR. ALBERT MOYER.—I tried to point out in my paper that the whole subject is still in an experimental stage, except in so far as we have treated concrete floors in office buildings, which, of course, have not been exposed to the elements, except those elements which the scrub-woman applies with the end of the mop. I should judge, however, from a practical standpoint, that the age of the concrete might affect the penetration, because a thin solution of sodium silicate would be introduced more deeply into the pores in old than it would in new concrete. In other words, the porosity of the concrete is an element that would assist; but that is rather a property of concrete which has to do more with mechanical workmanship than with the chemical side, which latter I think we can leave to the able hands of Mr. Cushman.

MR. HENRY S. SPACKMAN.—I should like to say that I have done some work in connection with the use of sodium silicates—more particularly with hydrous-silicic acid without the soda—which may possibly explain why the addition or mixing of sodium silicate with cement is dangerous. We discovered that a very weak solution of hydrous-silicic acid would absolutely prevent the hydration of lime. If a lump of quicklime is dropped in a beaker in which has been dissolved some gelatinous silica, and is left there several months, it will not hydrate. It is quite possible that in mixing sodium silicate with Portland cement, a coat or varnish of silica is formed which possibly combines with the surface of the cement and prevents further hydration. It certainly has that effect on lime. I have used the same treatment for floors which dry out too quickly, and the effect is to harden them and give them strength; but I have found, possibly owing to the cement acting as a filter, that while water may penetrate, the silicic acid which stays on the surface will gradually wear off and require a second treatment. It may not be noticed for possibly two or three years, but I do not think the ordinary top coat of a cement floor is sufficiently porous to allow the silica acid itself to penetrate to any great depth. **Mr. Spackman.**

MR. R. H. GAINES.—In the laboratory of the New York Board of Water Supply, we have had a little experience with sodium silicate as a means of waterproofing concrete, and the results were almost invariably unsatisfactory. The failure of the sodium silicate to bring about satisfactory results was perhaps due to the fact that sodium silicate is itself a colloidal solution, and thus prevents the ordinary development of a colloidal condition on the surfaces of the particles of cement, and hinders the chemical action that would normally take place, the result being that not only is the cement reduced in strength but the waterproofing effect is not noticeable. **Mr. Gaines.**

MR. C. M. CHAPMAN.—I want to confirm the experiments just referred to. Westinghouse, Church, Kerr and Company have made a series of experiments on the waterproofing of cements and concretes, and our experience has been the same: namely, that painting with a solution of waterglass is not at all effective as a waterproofing process. **Mr. Chapman.**

Mr. Low. MR. FRANK S. LOW.—I should like to ask Mr. Moyer how many coats he found it necessary to give his floors, and what length of time he allowed between coats.

Mr. Moyer. MR. MOYER.—The solution has to be thin enough to penetrate, and a number of coats must be applied, allowing a sufficient time between successive coats for the surface to dry, so that the next coat will penetrate. The number of coats required will depend upon the porosity of the concrete. The coats are applied at intervals of 24 to 36 hours, until the final coat is flush with the surface.

Mr. White. MR. G. D. WHITE.—May I ask how long a period of time must elapse after the application of sodium silicate to render the surface waterproof?

Mr. Moyer. MR. MOYER.—I have not stated in the paper that the surface had been made waterproof; that is a matter for further experiment. But it certainly has prevented the easy abrasion of the floors. If you should rub the sole of your shoe across a cement floor two or three times, you would find a considerable amount of dust beneath your foot. I think that by that method a spot in the floor might be abraded to the depth of a quarter of an inch in the course of an hour or two.

Mr. Boynton. MR. C. W. BOYNTON.—Then it would seem that those particles which were sufficiently loose to be rubbed off are cemented together by this treatment?

Mr. Moyer. MR. MOYER.—It probably serves to do a part of the work that the cement was not allowed to do.

TESTS OF REINFORCED CONCRETE COLUMNS SUBJECTED TO REPEATED AND ECCENTRIC LOADS.

By M. O. Withey.

Among some of the interesting tests carried on at the Materials Testing Laboratory of the University of Wisconsin during the past year, are those made on some very strong spirally-reinforced concrete columns. This paper reports some of the results obtained from tests of twelve of these columns. A more complete report of all unpublished results of reinforced concrete column tests is now being prepared for publication.

For assistance rendered in making these tests and in preparing the results, due acknowledgment is hereby made to Mr. J. B. Kommers of the Mechanics Department and to Messrs. O. W. Storey, F. E. Bates, O. Lupinski and H. E. Pulver, students in engineering. The Universal Portland Cement Company donated the cement used in making the specimens.

The materials used in fabricating the test pieces will now be considered. A local crushed limestone screened to pass a $1\frac{1}{4}$-in. mesh and having the dust removed, was used in making the concrete. It weighed 80 lbs. per cu. ft., and contained 52 per cent. voids. A well-graded clean sand weighing 107 lbs. per cu. ft. and containing 36 per cent. voids was furnished from a pit near Janesville, Wisconsin. Tests on the cement, made in accordance with the standard specifications of this Society, showed it to be satisfactory. Table I contains data derived from tension tests of the steel employed. The make-up of the spirals was similar to those described in the paper presented in 1909.*

Concrete or mortar was proportioned by volume, measured loose, cement being assumed to weigh 100 lbs. per cu. ft. Volumes were measured by weighing. After the materials had been mixed dry for about one-half minute in a No. 0 Smith batch-mixer, about 10 per cent. of water, based upon the total weight of

* *Proceedings*, 1909, Vol. IX, pp. 469-489.

dry materials, was added through pipes leading to the mouth and hopper of the mixer. Three minutes of mixing was sufficient to furnish a homogeneous wet concrete which would flow around the reinforcement.

The general characteristics of the columns are given in Table II. As it was thought desirable to study the properties of the columns within the spiral, the galvanized iron molds were fitted very closely to the spiral, so that there was only a thin shell of concrete encasing the metal. No account of this shell has been made in any of the computations which follow.

In making the columns, the longitudinal rods were spaced at equal distances apart and wired to the inner circumference of the spiral to prevent displacement in pouring. The forms, with the

TABLE I.—TENSION TESTS OF STEEL USED IN COLUMNS.

Number of Tests.	Approx. Size of Bar, ins.	Area, sq. ins.	Stress at Yield Point, lbs. per sq. in.			Ult mate Strength, lbs. per sq. in.		
			Maximum.	Minimum.	Average.	Maximum.	Minimum.	Average.
31	$\frac{7}{8}$	0.586	39,400	34,700	37,400	66,700	61,100	64,330
2	$\frac{7}{8}$	0.614	41,500	41,200	41,350	61,000	58,500	59,750
16	$\frac{3}{4}$	0.1964	40,600	37,000	39,670	60,300	55,000	57,800
8	$\frac{11}{16}$	0.3755	38,600	35,100	37,200	58,200	55,000	56,300
12*	$\frac{3}{16}$	0.0255	83,000	72,000	78,400	122,000	110,000	115,400

reinforcement inside, were then set upon planed cast-iron bed plates which were carefully leveled before the columns were poured. One compression cylinder 6 ins. in diameter and 18 ins. long was cast in an iron mold from every batch of concrete. A day or two after pouring, the columns and cylinders were capped with a thin layer of 1 : 1 mortar. While the mortar was still soft, a cast-iron bed plate was placed upon it and carefully leveled, care being taken to see that the depth of the mortar over the ends of the vertical reinforcement was made as small as possible. After six days the forms were removed from the specimens, which were then wet twice a day for one week and then sprinkled once a week until tested.

The columns were tested in the 600,000-lb. hydraulic testing machine in the laboratory. The lower head of this machine is rigidly fixed to the piston rod of a hydraulic jack, while the upper

*Tests on No. 7 high-carbon steel wire from spirals.

head is free to adjust itself to the specimen through a ball and socket joint. The columns were bedded at each end on cast-iron plates covered with a thickness of blotting paper.

In making the eccentric loading tests, the upper adjustable head was replaced by blocks *A*, *B*, and *C*, shown in Fig. 1.* These blocks were held in place, while the column was being adjusted

TABLE II.—PROPERTIES OF COLUMNS TESTED.

All columns 8½ ft. long and 10¼ to 10½ ins. in diameter; 1 per cent. spiral reinforcement of No. 7 high-carbon steel wire, 1-in. pitch.

Col. No.	Longitudinal Reinforcement.	Long. Reinforcement, per cent.	Total Area Inside of Spiral (*A*), sq. ins.	Proportions.	Age at Test, months.	Kind of Loading.
X1	None.	0	82.6	1 : 1⅜ : 3¼	2	Repeated.
X2	"	0	84.6	"	2	Repeated and constant.
Y1	8 ⅞-in. round rods.	5.7	84.6	"	2	Repeated.
Y2		5.8	82.6	"	2	Constant and repeated.
AA1	8 ½-in. round rods.	1.9	84.6	1 : 1⅓	2	Central.
					5	Eccentric.
AA2		1.9	84.6	"	2	Central.
					5	Eccentric.
AB1	8 11/16-in. round rods.	3.6	82.6	"	2	Central, repeated.
					5	Eccentric.
AB2		3.5	84.6	"	2	Central, repeated.
					5	Eccentric.
AC1	8 ⅞-in. round rods.	5.8	82.6	"	2	Central.
					5	Eccentric.
AC2		5.6	86.6	"	2	Central, repeated.
					5	Eccentric.
AD1	8 ⅞-in. round rods.	5.7	84.6	"	5	Eccentric
AD2		5.6	86.6	"	5	Eccentric.

in position, by a cradle not shown in the figure. Before putting the column in the machine, the vertical line on the block *P* was placed in a plane half way between the uprights, and the top surfaces of the blocks *E* and *F* were held approximately horizontal by means of the jacks *J*. The column was then swung in place

* Acknowledgment is hereby made to the *Engineering Record* for the cuts used in this paper.—ED.

and plumbed by the jacks. The plate *F* supporting the column was then moved by means of the screws *S* until measurements between the sides of the machine and the column indicated that the desired amount of eccentricity of the load had been made. After adjusting the eccentricity, the piston head of the machine was raised until the column just supported the top blocks *A*, *B*, and *C*. These blocks were then adjusted so that the line on *A* was co-

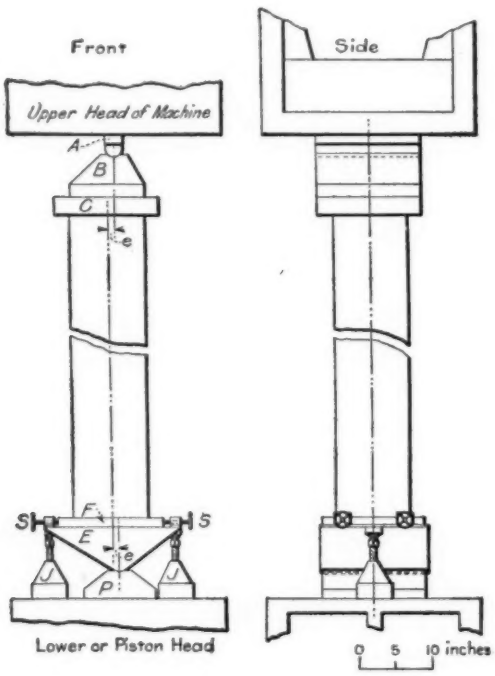


FIG. 1.—Eccentric Load Apparatus.

planar with the line on *P*. A small load was then applied and the jacks removed. In this manner the load was always applied axially with respect to the machine, while its eccentricity with respect to the column could be readily changed at the will of the operator.

Stresses were applied at the rate of approximately 500 lbs. per sq. in. per minute. The increments of load differed with the kind of column and the method of testing. In general, when the

TABLE III.—DATA ON STRENGTH OF COLUMNS SUBJECTED TO REPEATED OR TIME LOADINGS.

Loads are arranged in the order of their application.

Col. No.	No. of Repetitions of Stress.	Duration of Loads, minutes.	Average Unit-Stress, (P/A) lbs. per sq. in.	Unit Stresses at First Application of P/A, lbs. per sq. in.		Maximum Applied Load, lbs.	Ultimate Strength, lbs. per sq. in.	Compressive Strength of Cylinders, lbs. per sq. in.
				In Vertical Steel.	In Concrete.			
1	2	3	4	5	6	7	8	9
X1	3	.....	2,135	.....	2,135	.....	.....	.....
	4	.....	3,030	.....	3,030	.....	.....	.....
	4	.....	3,920	.....	3,920	.....	.....	.....
	.....	.....	.....	.....	.....	523,000	6,330	4,650
X2	4	.....	4,510	.....	4,510	.....	.....	.....
	.....	30	4,510	.....	4,510	.....	.....	.....
	.....	210	4,510	.....	4,510	.....	.....	.....
	.....	240	4,510	.....	4,510	.....	.....	.....
	.....	.....	.....	.....	.....	500,000	5,900	4,665
Y1	5	.....	2,260	10,800	1,750	.....	.....	.....
	2	.....	3,300	18,000	2,420	.....	.....	.....
	4	.....	3,300	.....	.....	.....	.....	.....
	5	.....	4,340	25,100	3,090	.....	.....	.....
	4	.....	7,300	*.....	.....	.....	.....	.....
	.....	.....	.....	.....	.....	617,500	7,300	4,220
Y2	.....	90	6,230	35,900	4,390	.....	.....	.....
	3	.....	7,480	*.....	.....	.....	.....	.....
	.....	.....	.....	.....	.....	617,509	7,480	4,120
AA1	.....	5	7,300	*.....	.....	617,500	Not broken	6,135
AA2	.....	15	7,300	*.....	.....	617,500	"	7,440
AB1	.....	25	7,480	*.....	.....	617,500	"	6,340
	1	4	7,480	.....	.....	.....	"	.....
AB2	.....	20	7,300	*.....	.....	617,500	"	6,435
	1	16	7,300	*.....	.....	.....	"	.....
AC1	.....	26	7,480	*.....	.....	617,500	"	6,075
AC2	.....	20	7,140	*.....	.....	617,500	"	5,835
	2	.....	7,140	.....	.....	.....	"	.....

load was being progressively increased, the increments were either 15,000 lbs. or 30,000 lbs. Measurements of longitudinal and lateral deformations were made with the same copper-wire dial compressometers and collar device, respectively, which were described last year. In the time-loading tests, changes of temperature in the room probably affected the results, but from the

*Beyond yield point. A few small cracks along the spacing bars were visible on Columns AA1-AC2.

small change in thermometer readings and the fact that the wire was insulated, it does not seem necessary to make any correction in the dial readings. When eccentric-loading tests were being made, especial care was taken to note the positions of all wires with reference to the column, as this is of vital importance if an accurate computation of the deformations at various points in the cross section of the column is to be obtained.

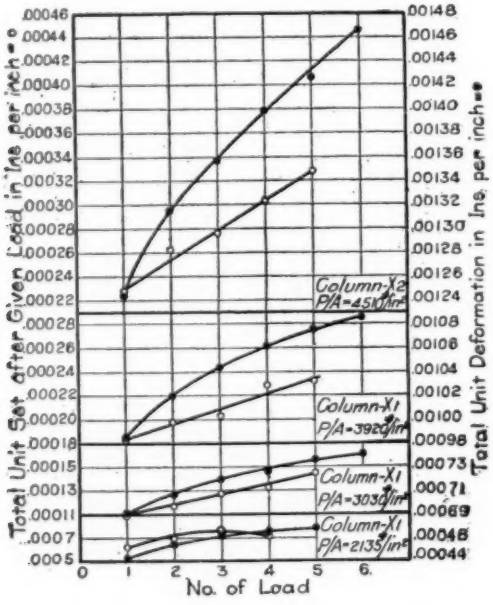


FIG. 2.—Set-Repetition and Deformation-Repetition Curves for Columns X_1 and X_2.

Table III contains data on the strength of columns subjected to repeated or time loadings. The main tests under these conditions were made on Columns X_1, X_2, Y_1, and Y_2. The other columns were not built to be tested in this way, but owing to their high strength it was found impossible to crush them in the ordinary manner, so repetition and time loadings were resorted to as shown. They are placed in this table to show briefly how they were tested before being subjected to eccentric loadings. Stresses in the steel were obtained by multiplying the deformations per unit of length by 30,000,000 lbs. per sq. in., the assumed modulus for the steel.

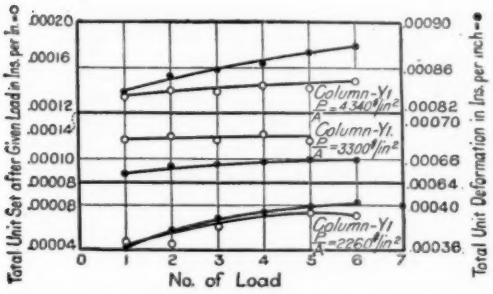


FIG. 3.—Set-Repetition and Deformation-Repetition Curves for Column Y1.

Fig. 2 shows several sets of curves drawn for Columns X1 and X2, with the number of repetitions as abscissas and the deformations and sets as ordinates. The value of P/A which was repeated is indicated in each portion of the figure. In Fig. 3 similar sets of curves have been drawn for Column Y1. Fig. 4

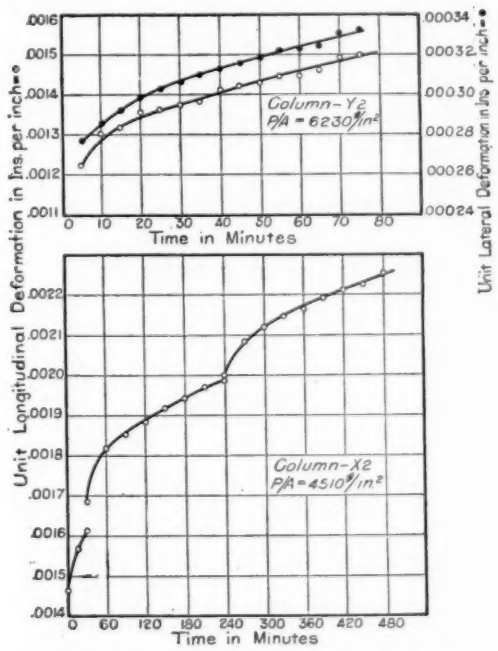


FIG. 4.—Time-Deformation Curves for Columns X2 and Y2.

contains deformation-time curves for Columns X2 and Y2, for values of P/A of 4,510 lbs. per sq. in., and 6,230 lbs. per sq. in., respectively. The breaks in the continuity of the curve for Column X2 are due to the fact that the loading was stopped twice, as indicated in Division 3 of Table III. After the first application for thirty minutes, the load was released and re-applied two days later for a period of three and one half hours. It was then released for one and one half hours and applied again for four hours. Subsequently the column was continuously loaded until it failed at the load indicated in Division 7 of Table III.

As it was found impossible to break Columns AA1 to AD2

TABLE IV.—DATA ON STRENGTH OF COLUMNS SUBJECTED TO ECCENTRIC LOADINGS.

Loads are arranged in the order of their application.

Col. No.	Longitudinal Reinforcement, Per cent.	Maximum Applied Load, lbs.	Maximum Value of P/A, lbs. per sq. in.	Load at Yield Point, lbs.	P/A at Yield Point, lbs. per sq. in.	Comp. Strength of Cylinders, lbs. per sq. in.	Eccentricity of Load, ins.
1	2	3	4	5	6	7	8
AA1	1.9	617,500	7,300	464,000	5,390	6,135	0
		540,000	*6,390	333,000	3,940	.....	1.0
AA2	1.9	617,500	7,300	514,000	6,080	7,440	0
		601,000	*7,110	384,000	4,640	.....	1.0
AB1	3.6	617,500	7,480	514,000	6,230	6,340	0
		540,000	*6,545	335,000	4,060	.....	1.0
AB2	3.5	617,500	7,300	514,000	6,080	6,435	0
		594,000	*7,020	392,000	4,640	.....	1.0
AC1	5.8	617,500	7,480	542,000	6,590	6,075	0
		627,000	7,600	421,000	5,100	.....	0.5
		590,000	*7,150	.....	.....	.....	1.0
AC2	5.6	617,500	7,140	515,000	5,940	5,835	0
		595,000	*6,890	351,000	4,060	.....	1.0
AD1	5.7	157,000	1,850	.....	.....	6,795	0
		157,000	1,850	.....	.....	.....	0.5
		157,000	1,850	.....	.....	.....	1.0
		157,000	1,850	.....	.....	.....	1.5
		420,000	*4,965	244,000	2,890	.....	2.0
AD2	5.6	275,000	3,180	.....	.....	6,670	0
		275,000	3,180	.....	.....	.....	0.5
		275,000	3,180	.....	.....	.....	1.0
		275,000	3,180	.....	.....	.....	1.5
		275,000	3,180	246,000	2,840	.....	2.0
		481,000	*5,560	275,000	3,180	.....	1.5

* Failed.

TABLE V.—STRESS AT YIELD POINT AND ELASTIC PROPERTIES OF COLUMNS AA1 TO AD2.

Col. No.	Longitudinal Reinforcement, per cent.	At P/A = 2,000 lbs. per sq. in. Values of			Comp. Strength of Cylinder., lbs. per sq. in.	Stresses at Yield Point, lbs. per sq. in.		Eccentricity of Load, ins.
		E, lbs. per sq. in.	$n = \frac{Es}{Ec}$	μ		Long. Steel.	Concrete.	
1	2	3	4	5	6	*7	8	9
AA1	1.9	5,800,000	5.6	0.20	6,135	32,000 42,000	4,890	0 1.0
AA2	1.9	5,800,000	5.6	0.18	7,440	37,500 42,000	5,480	0 1.0
AB1	3.6	6,200,000	5.7	0.21	6,340	35,400 37,500	5,150	0 1.0
AB2	3.5	5,800,000	6.1	0.16	6,435	35,100 40,200	5,030	0 1.0
AC1	5.8	6,100,000	6.4	0.16	6,075	36,000 35,600 40,200	4,760	0 0.5 1.0
AC2	5.6	6,200,000	6.4	0.19	5,835	32,200 34,200	4,400	0 1.0
AD1	5.7	5,700,000	7.1	0.14	6,795	 33,300	....	0 2.0
AD2	5.6	5,200,000	8.0	0.13	6,670	..... 34,800 34,800	....	0 2.0 1.5

by a central loading, the rig shown in Fig. 1 was employed to test them under loadings eccentrically applied. Data on the strength of the columns thus tested are given in Table IV. In selecting the values given for the yield point, the determining factors were the stresses at which the stress-deformation curves showed a perceptible change of curvature, the yield point of the longitudinal steel, and the appearance of cracks along the spacing straps on the spiral. Under eccentric loadings, the values of P/A at the yield point were determined from evidence furnished by the most-stressed fibers of concrete and longitudinal steel.

The yield point of spirally-reinforced concrete columns becomes more indistinct and less well-defined as the stiffness and strength of the concrete employed increases. This is due both to

* Values in Division 7 are computed from the deformation in the center fiber of that steel bar which was most stressed.

the decrease in the rate of curvature of the stress-deformation curve of the concrete and the decrease in the value of n. It is evident from Table V that the compressive strength of this rich concrete was not developed at the same time as the yield point of the longitudinal mild steel. Consequently the yield point of such columns

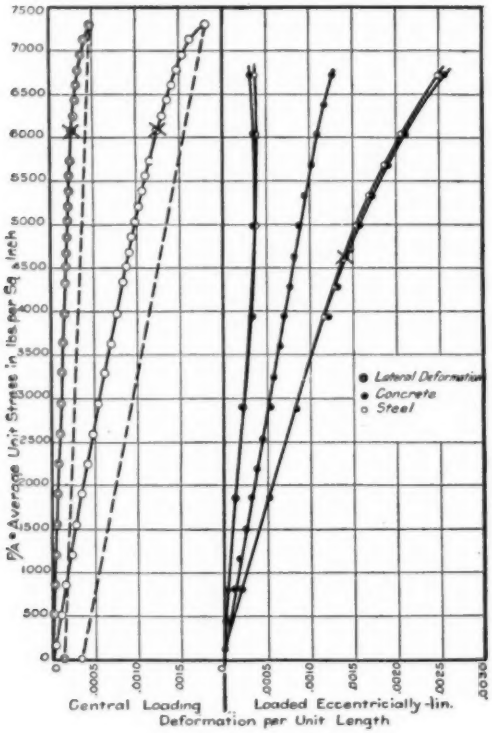


FIG. 5.—Stress-Deformation Curves for Column AA_2.

as these is chiefly dependent upon the latter when mild steel is used.

From Division 3 of Table V a comparison or estimation of the stiffness of Columns AA_1 to AD_2 may be made. The values of n tabulated in Division 4 of this table show that a large amount of longitudinal steel is not advantageous—theoretically, at least—in columns made of such rich concrete or mortar. Poisson's ratio or the factor of lateral expansion, μ, is considerably higher for

this grade of mortar than for the 1:2:4 concrete tested at the laboratory last year. However, the proportionate amount of additional strength furnished by the spiral in these strong mortar

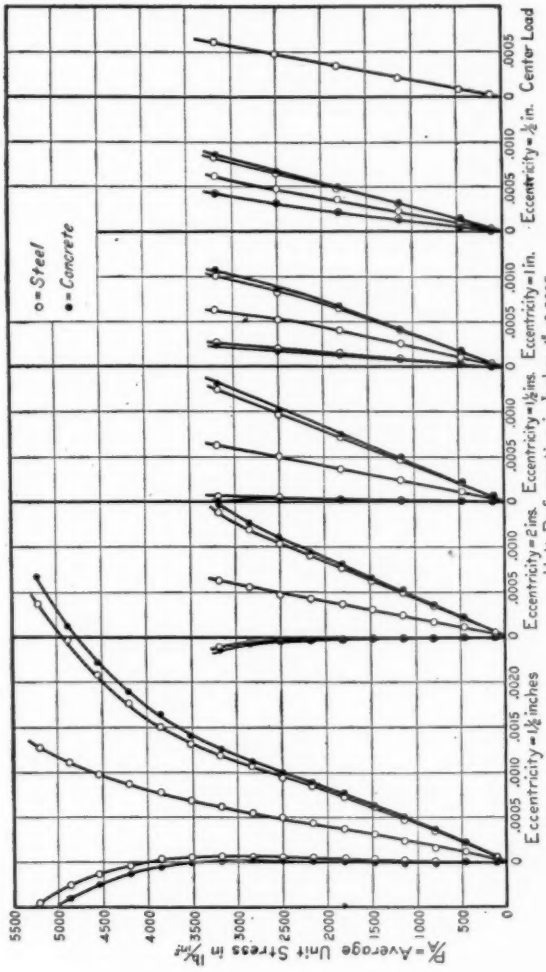

o = Steel
• = Concrete
P/A = Average Unit Stress in lb/in²
Eccentricity = 1½ inches
Eccentricity = 2 ins.
Eccentricity = 1½ ins.
Eccentricity = 1 in.
Eccentricity = ½ in.
Center Load
Unit Deformation in Inches 1" = 0.0005

FIG. 6.—Stress-Deformation Curves for Column AD2, Eccentric Loading.

columns is not materially increased, because a decrease in the value of n counteracts the effect of the increase in μ.

Fig. 5 shows the curves between P/A and the unit-deformations for both central and eccentric loadings for column AA2.

The crosses on the curves correspond with the stresses at the yield point. This column contained the strongest mortar of any tested, and its P/A-deformation curves show how remarkably stiff these columns were. Passing from left to right, the five sets of curves drawn for eccentric loadings represent the P/A-deformation curves for (1) the fiber of concrete furthest from the load, (2) the center fiber of the steel rod furthest from the load, (3) the fibers at the axis of the column, (4) the center fiber of the steel rod nearest the load, and (5) the outer fiber of concrete nearest the load.

Fig. 6 contains the P/A-deformation curves for Column AD2, in testing which four different eccentricities were tried. Similar curves were obtained from tests made on Column AD1.

These eccentric-loading tests afford an opportunity to compare theoretical stresses obtained by a modification of the formula

$$S = \frac{P}{A} \pm \frac{Mc}{I}$$

with the stresses calculated from deformations. In using the above formula proper allowance must be made for the steel in computing A and I. As used, it becomes

$$f_c = \frac{P}{A[1 - p(1-n)]} \pm \frac{Pec}{pA(n-1)\frac{r_s^2}{2} + \frac{Ar^2}{4}}$$

In this formula f_c = stress in concrete fiber considered; P = load; A = total area inside of spiral; p = longitudinal steel ratio; n = ratio of modulus of elasticity of steel to that of concrete; e = eccentricity of load P; c = distance from the axis of the column to the fiber considered, measured along the line of the eccentricity; r_s = radius of the centers of longitudinal steel bars; and r = radius of spiral. The stresses in the steel were computed by using the proper value of c and multiplying f_c by n. The formula assumes that the longitudinal steel is in the form of a thin pipe and makes no allowance for bending. However, the errors thus introduced are small for these columns.

Fig. 7 shows the theoretical curves and the plotted points calculated from deformations for Columns AD1 and AD2, when the

eccentricities were 2 ins. and $1\frac{1}{2}$ ins., respectively. The single-primed letters refer to stresses on the outer fiber of concrete or the center fiber of the steel rod nearest the load, and the double-primed letters refer to stresses on the corresponding fibers farthest from the load. In computing the values obtained from deformations, the same value of n was used as in obtaining the theoretical line. This value of n in all cases was computed from the stress-deformation curve from a central loading of the column considered.

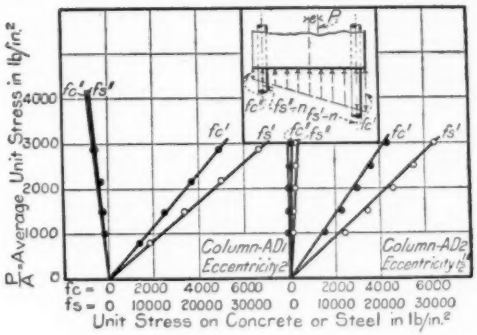


FIG. 7.—Comparison of Theoretical and Actual Stresses, Eccentric Loading.

The above formula may be written

$$f_c = \frac{P}{A}(K \pm em)$$

in which K and m are constants. Using the plus sign, and average values for K and m, it becomes for these columns

$$f_c = \frac{P}{A}(0.74 + 0.49e)$$

or

$$\frac{P}{A} = \frac{f_c}{0.74 + 0.49e}$$

which is the equation of an hyperbola, in which P/A and e are the variables.

In Fig. 8 the quantities P/A have been calculated with constant values of f_c on the most stressed concrete fiber and for different eccentricities. The two lower curves are theoretical curves derived from the last equation, while the points repre-

sent values derived from deformations. The curves refer to values obtained from Columns AC and AD. The lower curve is for Columns AD1 and AD2 only. The upper curve has been drawn through the plotted values of P/A at the ultimate load and, as will be noted, is quite similar to the theoretical curves drawn.

Some of the conclusions which appear to follow from these tests are noted in the succeeding paragraphs.

1. The remarkably great strength and stiffness of many of the columns forcibly emphasizes the advantages of rich mixtures.

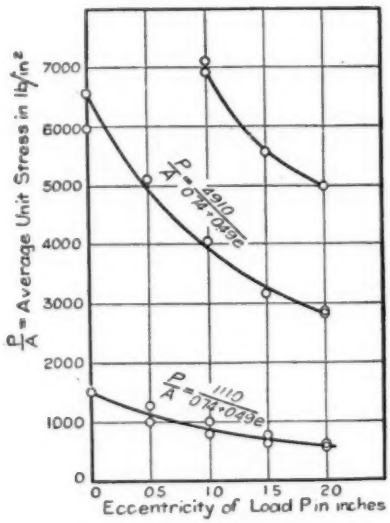


FIG. 8.—Average Stress-Eccentricity Curves.

In such columns, when centrally loaded, large percentages of either longitudinal or spiral reinforcement do not seem necessary, on account of the small value of n and the high cost of steel compared with the cost of cement. Longitudinal steel in larger amounts is of more advantage, however, in eccentrically loaded columns, especially in cases where tension may exist on one side of the column.

2. The amount of data presented on repeated or time loadings is far too little to warrant drawing definite conclusions as to the limiting stress for repeated loadings which will hold true for all kinds of columns and for an infinite number of repetitions, or for

a prolonged loading. However, it does appear from the tables and figures that there was practically no increase in set or deformation after a few repetitions of loads equal to 40 to 50 per cent. of the yield points of the columns tested.

3. The results also plainly indicate that there is considerable additional strength and toughness afforded by the spiral after the yield point of the longitudinal steel has been passed. That all of this additional strength may not be permanent is also suggested by the slope of the deformation-time curves for Columns X2 and Y2.

4. The close agreement between theoretical values and values derived from test data shows that the formula

$$S = \frac{P}{A} \pm \frac{Mc}{I}$$

commonly used in designing short homogeneous columns eccentrically loaded, may be applied to reinforced concrete columns, provided suitable allowance is made for the steel.

AN INVESTIGATION OF THE DISTRIBUTION OF STRESS IN REINFORCED CONCRETE BEAMS, INCLUDING A COMPARATIVE STUDY OF PLAIN CONCRETE IN TENSION AND COMPRESSION.

By A. T. Goldbeck.

In the spring of 1909, Messrs. J. T. Paxson and H. K. Preston, and in the spring of 1910, Messrs. J. J. Durfee, G. W. Hunt, F. H. Kelly, and F. H. Irmschler, Seniors at Lafayette College, undertook, with the assistance of the writer, a series of tests on reinforced concrete beams, in an effort to determine the magnitude and distribution of the horizontal fiber stresses. The general method of procedure used in this determination was as follows:

1. Deformations were measured in a number of horizontal planes in reinforced concrete beams under loadings of different magnitudes, and from these measurements unit deformations were calculated.

2. From tests of compression and tension specimens molded from the same batch of concrete that was used in making the transverse specimens, unit deformations corresponding to known loads were determined.

3. Assuming that the fibers in the beam were subjected to the same unit stresses that existed in the tension and compression specimens when under the same unit deformations, the stress distribution was found.

Materials.—In the series of 1909, a 1: 2: 4 mixture of concrete, proportioned by weight, was used for all specimens. Alpha Portland cement, bank sand, and 1½-in. crusher-run dolomite were mixed to a consistency such that water readily flushed to the top upon molding the specimens. The steel reinforcement consisted of plain rounds, having a yield point of about 35,000 lbs. per sq. in., and an ultimate tensile strength of 55,000 lbs. per sq. in.

The materials used in the 1910 series were of the same character as those previously described, except that the stone was 1-in. crusher-run dolomite instead of 1½-in.

Molding.—Each batch of concrete was of sufficient volume to make one transverse, one compression, and one tension specimen. The sand and cement were mixed dry until they had a uniform color. This mixture and the previously moistened stone were then combined. Water was added while the mixture was being turned, until the concrete thus formed was of a uniform, medium wet consistency. The specimens were molded in layers about 3 ins. thick, each layer being troweled and tamped with a light steel rod.

Specimens.—The transverse specimens were 8 ins. by 11 ins. in cross section and 13 ft. long, the center of the reinforcement

TABLE I.—DETAILS OF BEAMS.

Width = 8 ins. Distance from top of beam to center of steel = 10 ins.
Total depth = 11 ins. Span = 12 ft. Loads applied at third points.

Beam.	Reinforcement.			Proportions.	How Stored.	Age, days.
	Type.	Number of Rods.	Area, sq. ins.	Per cent.		
1	½-in. Rounds	3	0.588	0.736	1:2:4 (weight)	Air — 7 days Water—79 "	86
2	"	4	0.784	0.98	"	Air — 7 days Water—80 "	87
3	⅝ " "	3	0.922	1.15	"	Air — 7 days Water—73 "	80
4	"	4	1.23	1.53	"	Air — 7 days Water—70 "	77
5	¾ " "	3	1.33	1.66	"	Air — 7 days Water—55 "	62
6	"	2	0.883	1.10	"	Air — 7 days Water—45 "	52
D	⅝ " "	2	0.614	0.768	1:2:4 (volume)	Air	28
F	½ " "	4	0.784	0.98	"	"	"
G	⅝ " "	3	0.922	1.15	"	"	"
J	¾ " "	3	1.33	1.66	"	"	"
L	9/16 " "	4	0.99	1.24	"	"	"
N	¾ " "	3	1.33	1.66	1:3:6 (volume)	"	"
P	9/16 " "	4	0.99	1.24	"	"	"
Q	½ " "	4	0.784	0.98	"	"	"
T	⅝ " "	2	0.614	0.768	"	"	"
V	9/16 " "	2	0.497	0.618	"	"	"
X	⅝ " "	3	0.922	1.15	"	"	"

being placed 1 in. from the bottom. Cylinders 8 ins. in diameter and 16 ins. long were tested in compression. The tension specimens consisted of 8-in. cylinders with ends enlarged in diameter to 10 ins. to permit of gripping them.

Storage.—In the 1909 series all specimens were allowed to stand for 7 days in air, and were then stored in water until a few hours before testing. In the series of 1910 all specimens were stored in air, no attempt whatever being made to prevent their rapid drying out.

METHOD OF TESTING.

Concrete in Compression.—All compression specimens were tested in a 200,000-lb. Riehlé Machine. In order to insure a uniform bearing, plaster-of-Paris bedding was used on both ends of the specimen, with a spherical bearing block interposed between the moving head of the machine and the top bed of plaster. A compressometer of 12-in. gage length, reading to one ten-thousandth of an inch by electric contact, was used for measuring deformations. Deformation readings were taken on opposite sides of the specimen and the mean deformation calculated. The loads were applied in increments of 5,000 lbs. until the ultimate strength was reached. The machine was stopped after each increment had been applied, to permit of reading the compressometer.

Concrete in Tension.—Special tension pulling-heads were designed to grip the specimens used in this test. They consisted of cast-iron cylinders fitting over and gripping the enlarged ends of the specimen by means of split cast-iron collars screwed into contact with the shoulders on the specimen. The compressometer used for the compression tests was also utilized for measuring the tensile deformations. Difficulty was experienced in reading the extensions on account of the small increment in load rendered necessary by the low tensile strength of the concrete.

Transverse Tests.—The transverse specimens were tested on a span length of 12 ft., the loads being applied at the third points. A 400,000-lb. Riehlé Transverse Machine was used for all beam tests. The specimens were supported upon bearing blocks 2 ins. wide with beds of plaster of Paris interposing. They were lowered

into position while the plaster was still soft, insuring a firm, even bearing at the supports. At the third points, bearing blocks 2 ins. wide were set in soft plaster beds and on each block a 1½-in. steel roller was placed. The load was transmitted to the rollers through a pair of 3-in. I-beams, bolted together.

Fiber deformations were measured in six different planes along the sides of the beam, a unique type of fiber extensometer being employed. Steel balls 1 in. in diameter, such as are used in ball bearings, were clamped to the sides by U-clamps, there being twelve balls on each side. A 36-in. gage length was used. The deformations were measured by means of a micrometer rod consisting of a ¼-in. brass rod, pointed at one end and carrying a micrometer head at the other. Means were provided at each end of the micrometer rod for properly supporting it on the contact balls. The micrometer read to one one-thousandth of an inch directly and by estimation to one ten-thousandth of an inch. Electric contact was used with a telephone receiver in circuit. In many of the beams tested, deformations were also measured in the planes of the top and bottom fibers, the micrometer rods being supported on contact balls fastened to frames, clamped to the beam in a position such that the centers of the balls were in the planes of the top and bottom surfaces. This apparatus proved to be very satisfactory, both in ease of adjustment to the specimen and in accuracy. Duplicate readings could be taken by estimation to one ten-thousandth of an inch.

Deflections were read to one one-hundredth of an inch on a steel scale fastened to the side of the beam, the readings being indicated by a fine wire stretched between U-clamps attached over the points of supports.

Loads were applied in increments of 1,000 lbs., and extensometer readings were taken as quickly as possible to prevent undue change in the load during successive readings. Illustrated descriptions of the above-mentioned compressometer, fiber extensometer, and tension pulling heads will be found in this volume in a paper by J. M. Porter, entitled "Some Testing-Laboratory Accessories."*

* See pp. 563 ff.—ED.

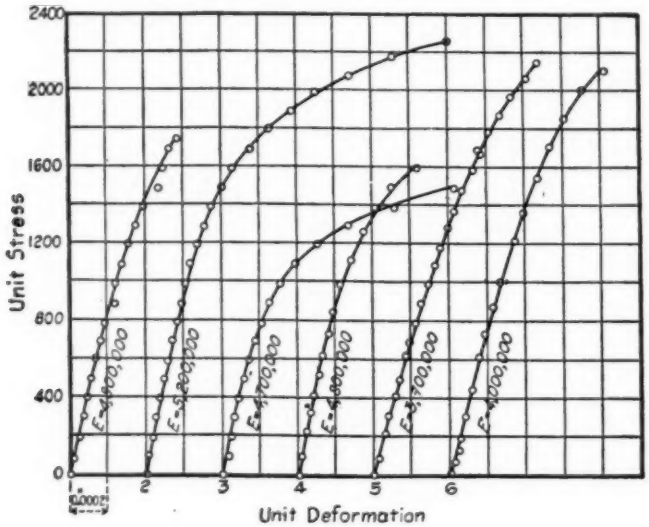


FIG. 1.—Compression Tests on 1:2:4 Concrete.

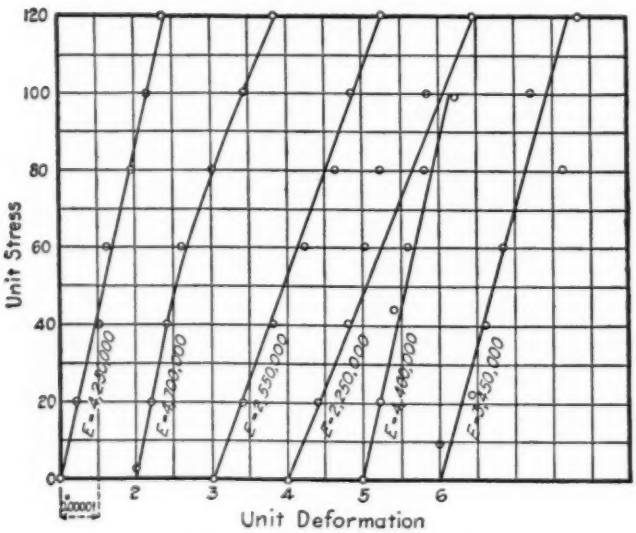


FIG. 2.—Tension Tests on 1:2:4 Concrete.

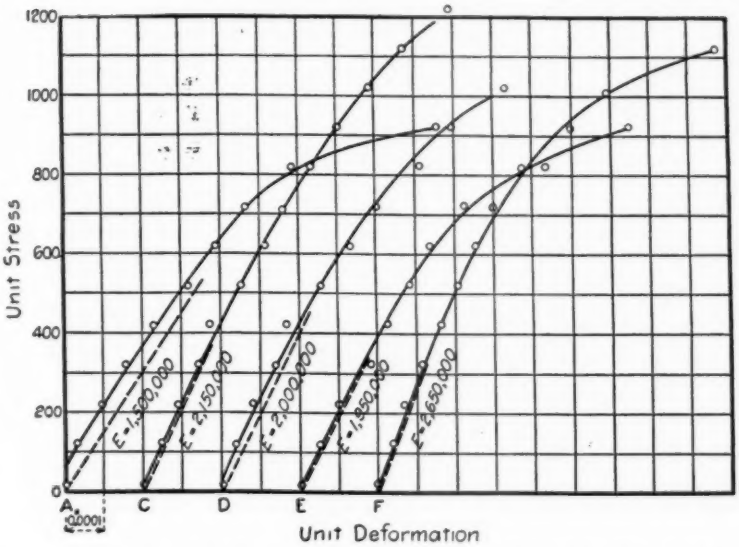


FIG. 3.—Compression Tests on 1:2:4 Concrete; Stored in Air 28 Days.

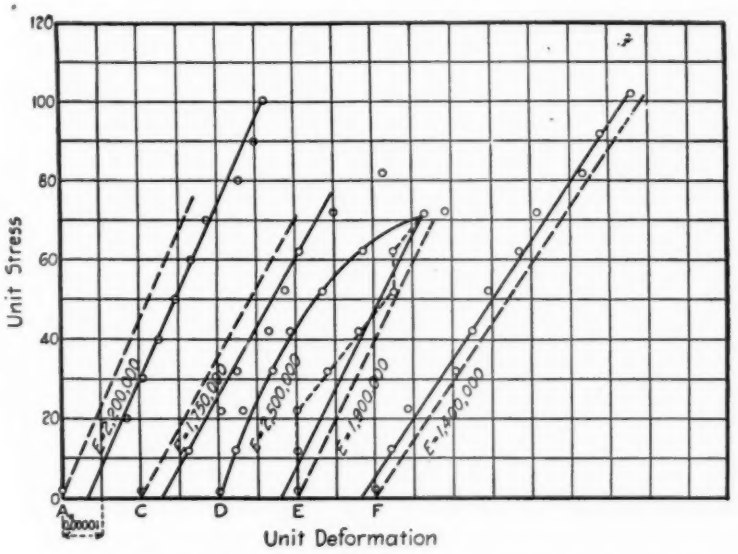


FIG. 4.—Tension Tests on 1:2:4 Concrete; Stored in Air 28 Days

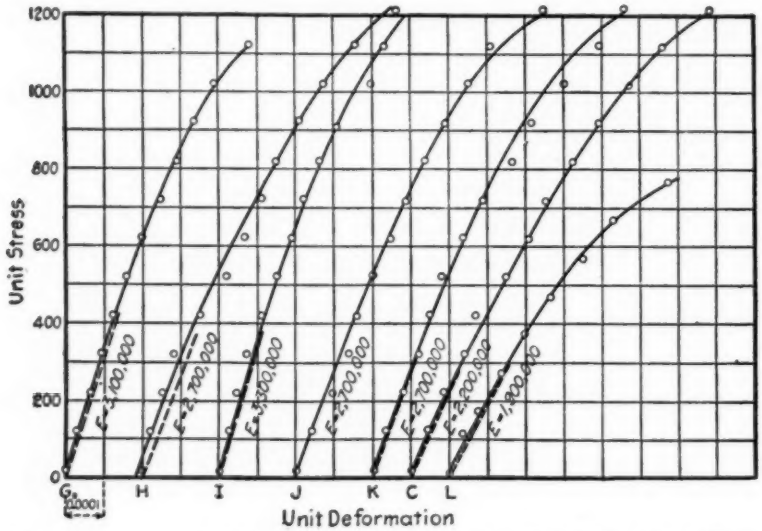


FIG. 5.—Compression Tests on 1: 2: 4 Concrete; Stored in Air 28 Days.

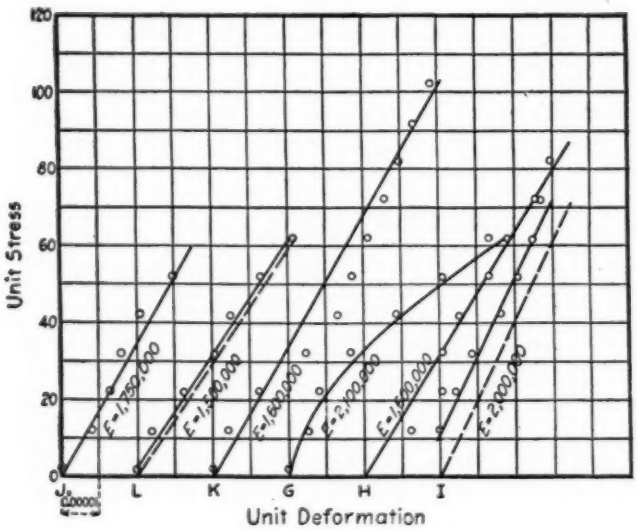


FIG. 6.—Tension Tests on 1: 2: 4 Concrete; Stored in Air 28 Days.

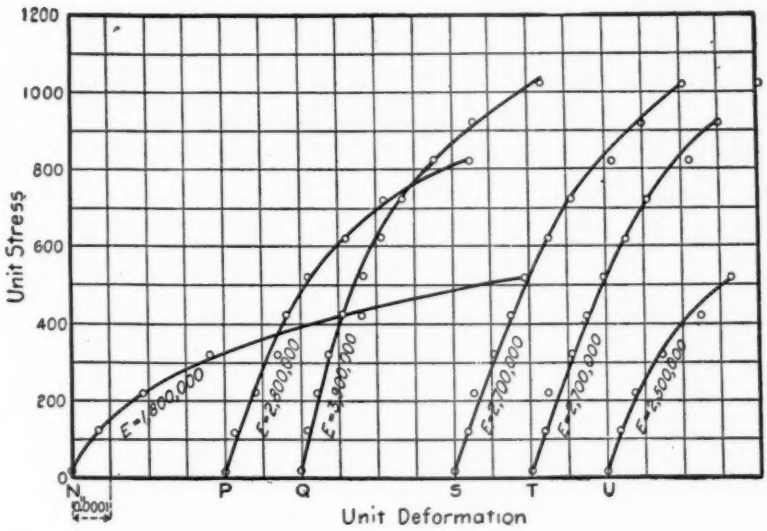


FIG. 7.—Compression Tests on 1:3:6 Concrete; Stored in Air 28 Days.

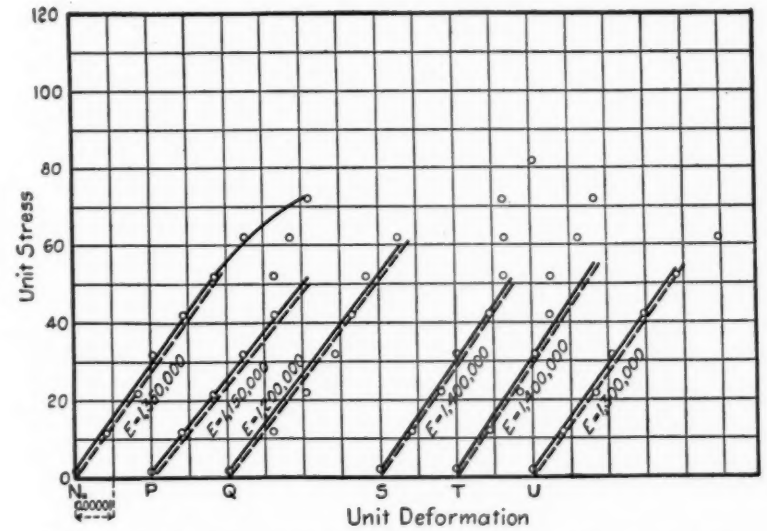


FIG. 8.—Tension Tests on 1:3:6 Concrete; Stored in Air 28 Days.

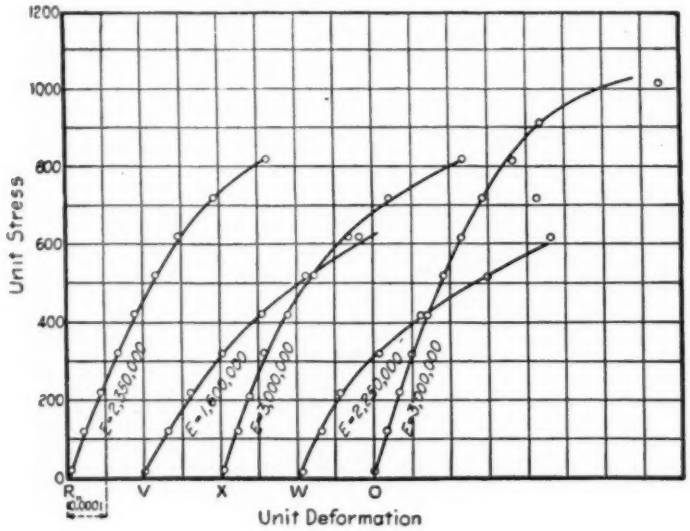


FIG. 9.—Compression Tests on 1:3:6 Concrete; Stored in Air 28 Days.

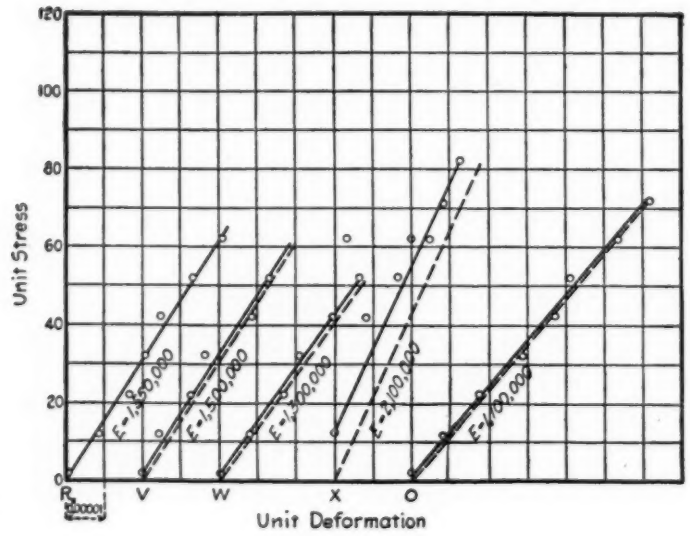


FIG. 10.—Tension Tests on 1:3:6 Concrete; Stored in Air 28 Days.

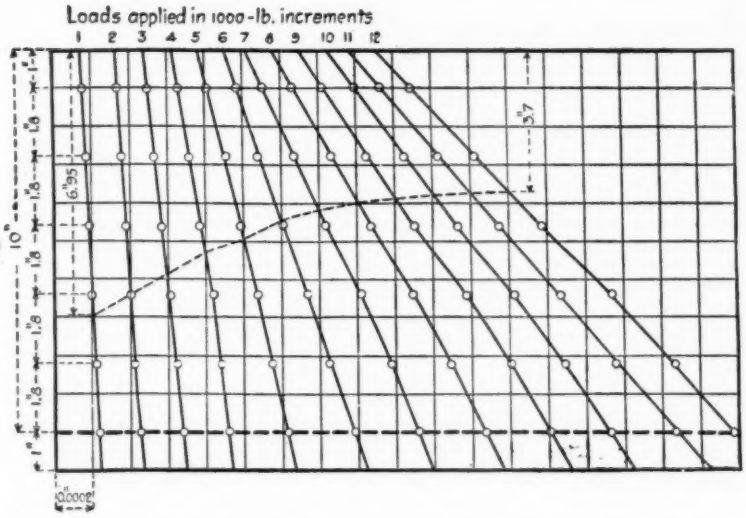


FIG. 11.—Curves of Unit Deformations for Beam 2; Reinforcement = 0.98 per cent.

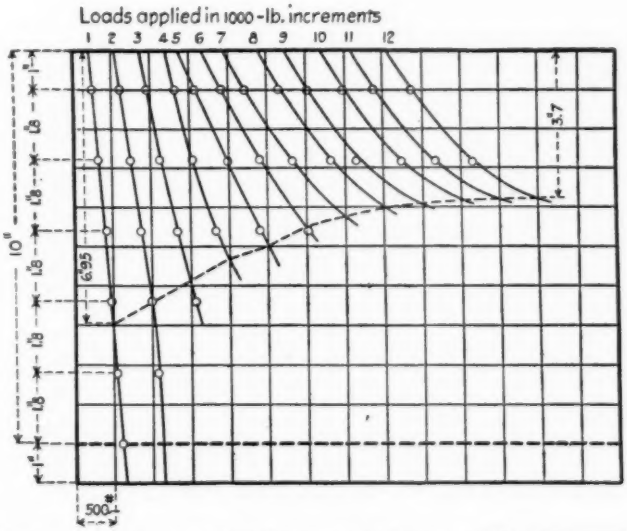


FIG. 12.—Curves of Unit Stresses for Beam 2; Reinforcement = 0.98 per cent.

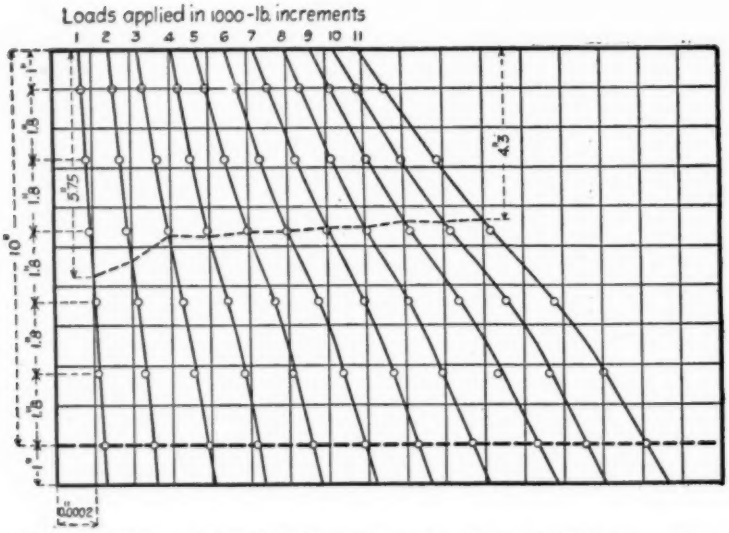


FIG. 13.—Curves of Unit Deformations for Beam 6; Reinforcement = 1.10 per cent.

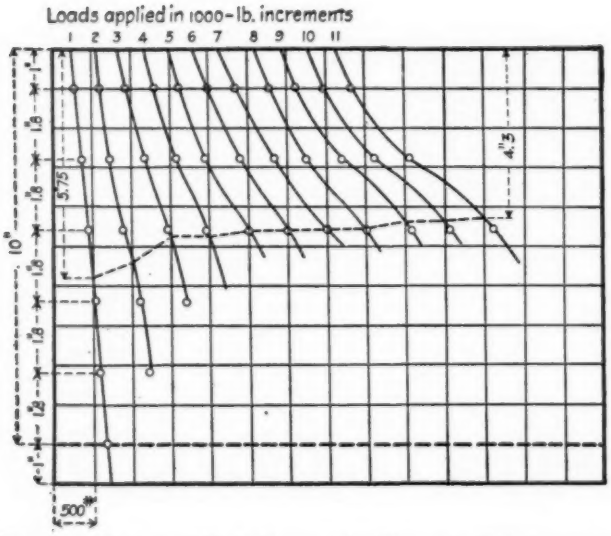


FIG. 14.—Curves of Unit Stresses for Beam 6; Reinforcement = 1.10 per cent.

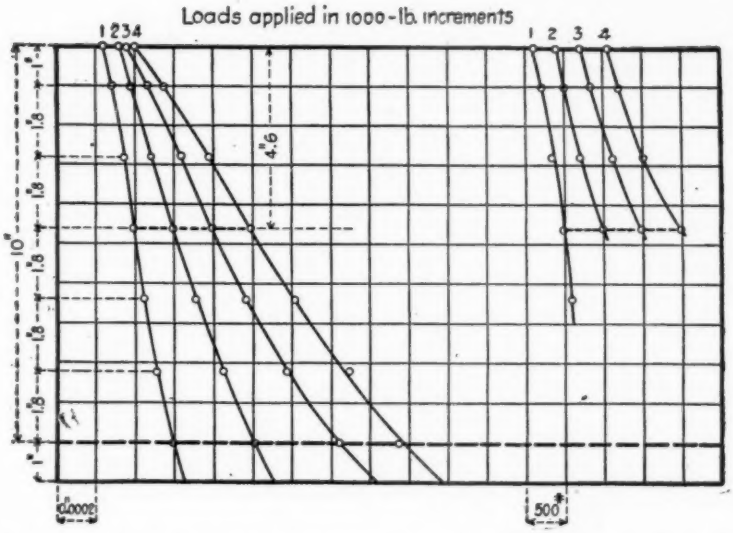


FIG. 15.—Curves of Unit Deformations and Unit Stresses for Beam D; Reinforcement = 0.768 per cent.

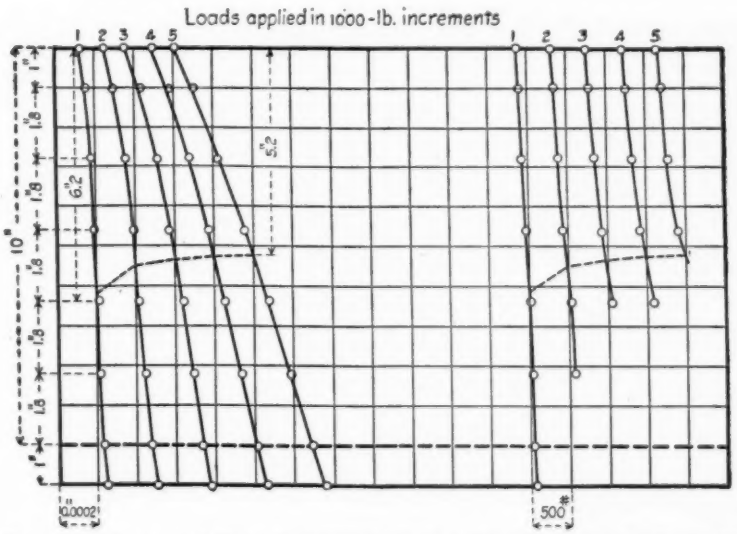


FIG. 16.—Curves of Unit Deformations and Unit Stresses for Beam N; Reinforcement = 1.66 per cent.

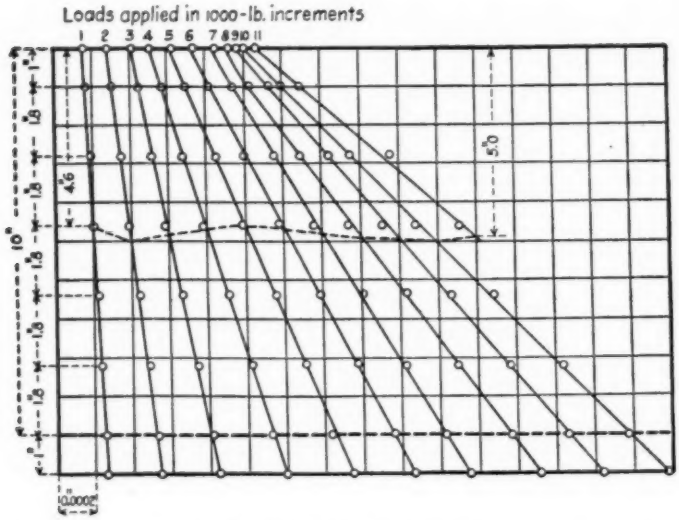


FIG. 17.—Curves of Unit Deformations for Beam L; Reinforcement = 1.24 per cent.

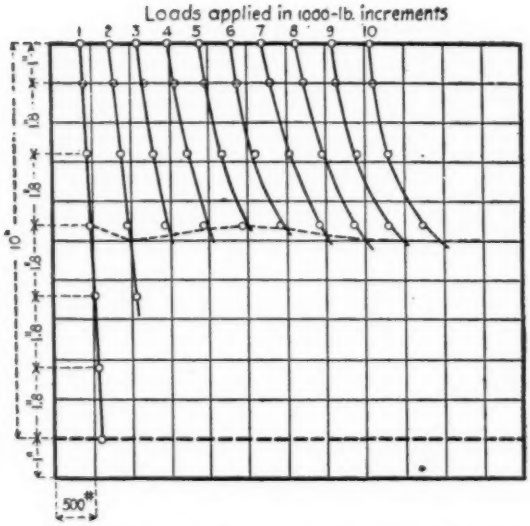


FIG. 18.—Curves of Unit Stresses for Beam L; Reinforcement = 1.24 per cent.

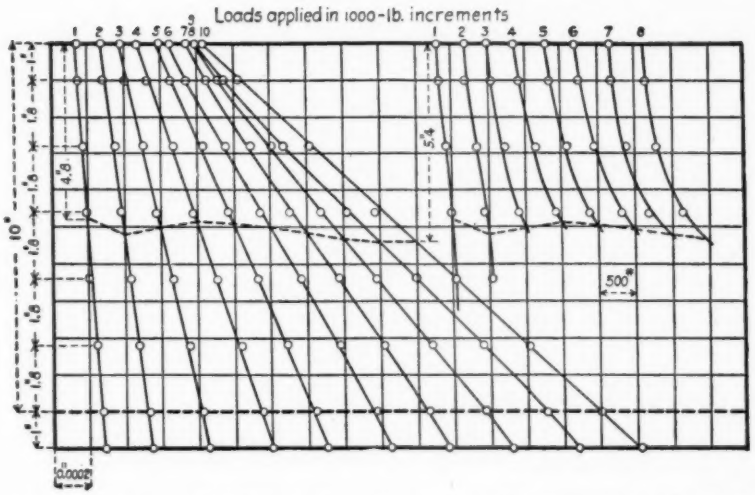


FIG. 19.—Curves of Unit Deformations and Unit Stresses for Beam P; Reinforcement = 1.24 per cent.

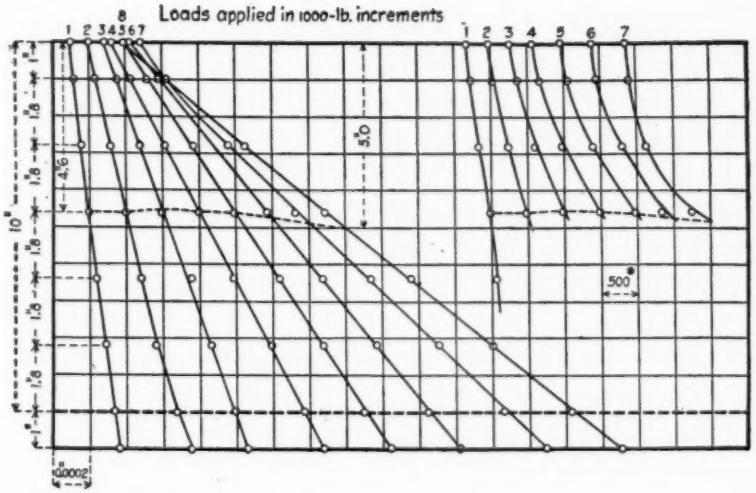


FIG. 20.—Curves of Unit Deformations and Unit Stresses for Beam T; Reinforcement = 0.768 per cent.

DESCRIPTION OF CURVES.

Micrometer readings in the same plane were averaged and the total deformations were calculated from the mean readings, no account being taken of the deformation of the beam under its own weight. Unit deformations were obtained by dividing the total deformations by the gage length, 36 ins.

Curves shown in Figs. 11, 13, 15, 16, 17, 19, and 20 were plotted, using unit deformations of the fibers of the beam as abscissas, the ordinates marking the planes in which the deformations were measured. For each curve, the origin of coordinates has been displaced to prevent the confusion of lines which would result if they were plotted from the same origin. Compressions have been plotted to the left and elongations to the right of the assumed origin. The point of intersection of each curve with a vertical through the origin marks the position of the neutral axis of the beam. These points have been connected by a dotted line.

The curves of unit stresses shown in Figs. 12, 14, 15, 16, 18, 19, and 20 were obtained by plotting the stresses corresponding to the measured deformations. It was assumed that like unit deformations in the tension and compression specimens and in the fibers of the beams were caused by corresponding unit stresses. It will be noted that the curves of stresses have been extended only far enough to include the maximum tensile strength of the concrete.

RESULTS OF TESTS.

Referring to the curves of unit deformation, it is seen that, for all practical purposes, they are straight lines, with a tendency to become concave upward above the neutral axis and concave downward below the neutral axis as the loading progresses. This curvature is more pronounced in the cases of the beams stored in water. Beams D, J, and N, stored in air, are positive exceptions to the rule.

The dotted curves of zero deformation, in the cases of Beams 1 to 6 (stored in water), rise under loading, the direction being rather erratic under the first few loads but having a distinctly upward gradual trend in the later stages of the test. Nothing definite can be said of the positions of the fibers of zero deformation in the

TABLE II.—COMPARISON OF THEORETICAL VALUES WITH VALUES MEASURED IN BEAMS.

Beam.	Per cent. of Reinforcement.	Loads, lbs.	Compression in Top Fiber, lbs. per sq. in.		Tension in Steel, lbs. per sq. in.		Total Stress, lbs.		Top of Beam to Neutral Axis.	
			Measured.	Theory.	Measured.	Theory.	Comp.	Tens.	Measured.	Theory.
1	0.736	1,000	220	185	1,460	4,680	5,890	3,207	6.1	3.73
		3,000	650	553	4,100	14,000	14,270	2,726	5.1	"
		9,000	1,900	1,660	36,500	42,000	32,800	21,450	3.5	"
2	0.98	1,000	310	168	1,100	3,550	8,620	2,811	6.95	4.15
		3,000	510	503	2,450	10,700	11,950	2,830	5.85	"
		12,000	1,840	2,020	36,30)	42,800	27,200	28,470	3.7	"
3	1.15	1,000	200	160	1,180	3,070	4,170	3,295	5.7	4.40
		5,000	700	795	5,940	15,300	16,800	5,555	5.1	"
		12,000	1,180	1,920	28,100	36,800	21,600	26,170	3.7	"
4	1.53	1,000	300	148	1,470	2,340	6,230	5,005	5.2	4.87
		3,000	650	436	2,720	6,400	14,780	6,50'	5.3	"
		16,000	1,700	2,370	34,200	37,400	42,300	42,320	4.5	"
5	1.66	1,000	200	145	640	2,160	5,200	3,670	6.4	4.98
		5,000	750	.722	4,420	10,800	18,000	6,460	5.75	"
		16,000	2,000	2,310	38,000	34,600	48,250	50,400	4.6	"
6	1.10	1,000	250	162	1,300	3,180	6,120	5,110	5.75	4.32
		3,000	660	487	5,200	9,520	13,624	6,080	4.72	"
		11,000	1,850	1,780	23,800	35,000	38,000	21,200	4.30	"
D	0.768	1,000	270	182	5,820	4,470	5,600	3,978	5.6	3.78
		2,000	560	364	12,300	8,940	11,400	7,550	"	"
		4,000	900	728	22,300	17,900	18,784	13,700	"	"
G	1.15	1,000	140	160	750	3,070	4,000	1,978	6.3	4.40
		5,000	700	795	4,920	15,300	16,160	4,818	5.55	"
		15,000	1,430	2,400	21,800	46,000	40,584	20,200	5.30	....
J	1.66	1,000	240	145	1,170	2,160	5,200	3,080	6.0	4.98
		3,000	610	435	3,900	6,500	11,270	8,094	5.7	"
		11,000	1,570	1,590	23,400	23,800	27,840	31,100	5.45	"
L	1.24	1,000	110	157	1,650	2,850	2,440	3,294	4.6	4.51
		6,000	680	940	16,800	17,100	....	....	4.7	"
		10,000	900	1,570	29,200	28,500	25,600	29,000	5.0	"
N	1.66	1,000	135	145	810	2,160	2,480	2,448	6.2	4.98
		....	....	....	....	....	....	....	....	....
		5,000	335	722	8,500	10,800	8,960	11,300	5.2	4.98
P	1.24	1,000	190	157	2,070	2,850	3,640	2,770	4.8	4.51
		5,000	700	785	13,490	14,200	17,440	13,300	4.9	"
		7,000	820	1,100	19,800	20,000	23,960	19,600	5.15	"
Q	0.98	1,000	310	168	2,040	3,550	6,560	2,720	5.2	4.15
		3,000	630	503	8,400	10,700	15,640	6,600	4.6	"
		7,000	1,040	1,170	23,300	24,800	27,040	18,400	4.8	"
T	0.768	1,000	320	182	3,000	4,470	6,160	2,280	4.6	3.78
		3,000	710	546	12,000	13,400	14,640	7,380	4.5	"
		7,000	1,110	1,270	33,000	31,300	31,280	20,300	4.9	"
V	0.618	1,000	250	195	4,680	5,480	4,920	2,400	4.6	3.47
		....	....	....	....	....	....	....	....	....
		4,000	700	781	25,500	21,800	16,088	12,600	4.6	3.47
X	1.15	1,000	240	160	1,500	3,070	5,280	2,020	5.15	4.40
		4,000	710	640	9,300	12,300	18,496	8,600	5.3	"
		6,000	830	960	17,100	18,400	23,120	15,800	5.25	"

cases of the remaining beams stored in air. In some of these beams the zero-deformation curve rises under loading; in some of them it drops. In general, however, in beams having a low percentage of reinforcement, the zero-deformation curve occupies a higher position than in those beams having a higher percentage of reinforcement. Notable exceptions to this rule occur in the cases of Beams L and P (1.24 per cent. reinforcement), in which the zero-deformation curves are higher than in Beams G and X (1.15 per cent. reinforcement).

Table II shows a comparison of the test results with results computed on the common theory of straight-line distribution of compressive stress and no tension in the concrete, using 2,000,000 for the modulus of elasticity of concrete in compression, and 30,000,000 for that of steel. It will be seen that the unit stress in the most remote fibers of the concrete as obtained by measurement, is, for the initial loading, more than the calculated stress, in all of the beams stored in water (Beams 1 to 6 inclusive), and likewise in most of the remaining beams stored in air. The tension in the steel under the initial loads, as obtained by measurement, is in all cases lower than that given by theory. Likewise, the position of the neutral axis is lower than the theoretical position.

To satisfy one of the laws of static equilibrium, the total compression in the concrete above the neutral axis should equal the total tension in the steel and the concrete below the neutral axis. The total compression and total tension under various loads were calculated for each beam. The total compression was obtained from the stress curves; the total tension was obtained by adding the measured tension in the steel to the tension that the concrete was capable of taking, as indicated by the tension specimen. Referring to the columns of total tension and total compression, it will be noted that for a load of 1,000 lbs., in but one beam is there even a fair agreement. In most of the beams the total compression greatly exceeds the total tension. In the later stages of the test the total compression accords more closely with the total tension, although the agreement is by no means exact.

Under these conditions it would hardly be fair to state that the curves of stresses as plotted represent the exact stresses in the beams, but the differences between successive curves should very

TABLE III.—COMPARISON OF CONCRETE IN TENSION AND COMPRESSION.

Proportions 1:2:4 (volume).
Stored 28 days in air.

Beam.	Compression.		Tension.	
	Strength, lbs. per sq. in.	Mod. of Elasticity (E).	Strength, lbs. per sq. in.	Mod. of Elasticity (E).
A	1,080	1,500,000	110	2,200,000
B	Not tested			
C	1,520	2,150,000	102	1,750,000
D	1,120	2,000,000	82	2,500,000
E	1,220	1,950,000	82	1,900,000
F	1,320	2,650,000	112	1,400,000
G	1,470	3,100,000	72	2,100,000
H	1,520	2,700,000	92	1,600,000
I	1,910	3,300,000	82	2,000,000
J	1,610	2,700,000	62	1,750,000
K	1,610	2,700,000	106	1,600,000
L	962	1,900,000	72	1,500,000
M	Not tested			
Average..	1,395	2,420,000	88.5	1,845,000

Tensile strength is 6.3 per cent. of compressive strength.
E in tension is 76.7 per cent. of E in compression.

TABLE IV.—COMPARISON OF CONCRETE IN TENSION AND COMPRESSION.

Proportions 1:3:6 (volume).
Stored 28 days in air.

Beam.	Compression.		Tension.	
	Strength, lbs. per sq. in.	Mod. of Elasticity (E).	Strength, lbs. per sq. in.	Mod. of Elasticity (E).
N	620	1,800,000	82	1,360,000
O	1,120	3,000,000	82	1,100,000
P	915	2,800,000	72	1,150,000
Q	1,110	3,900,000	72	1,200,000
R	920	2,350,000	72	1,550,000
S	820	2,700,000	72	1,400,000
T	1,220	2,700,000	82	1,400,000
U	720	2,500,000	72	1,300,000
V	820	1,600,000	72	1,500,000
W	720	1,300,000	62	1,300,000
X	920	3,000,000	92	2,100,000
Average..	910	2,510,000	75.6	1,395,000

Tensile strength is 8.8 per cent. of compressive strength.
E in tension is 55.6 per cent. of E in compression.

TABLE V.—COMPARISON OF CONCRETE IN TENSION AND COMPRESSION.

Proportions 1:2:4 (weight).

Beam.			Compression.		Tension.		Ratios of Ten. to Comp.	
Mark.	Age, in days.	How stored.	Strength, lbs. per sq. in.	Mod. of Elasticity (E).	Strength, lbs. per sq. in.	Mod. of Elasticity (E).	Strength.	E.
1	86	Air 7 Water 79	1,810	4,800,000	140	4,250,000	0.0773	0.89
2	87	Air 7 Water 80	2,345	5,200,000	120	4,700,000	0.0512	0.90
3	80	Air 7 Water 73	1,934	4,100,000	171	2,550,000	0.0884	0.625
4	77	Air 7 Water 70	1,720	4,800,000	145	2,250,000	0.0842	0.47
5	62	Air 7 Water 55	2,304	3,700,000	159	4,400,000	0.0690	1.19
6	52	Air 7 Water 45	2,165	4,000,000	203	3,450,000	0.0938	0.865
				Average.....			0.0775	0.823

Tensile strength is 7.75 per cent. of compressive strength.
E in tension is 82.3 per cent. of E in compression.

closely represent the increase in stress under the increasing loads. The lack of agreement between total compression and tension in the first stages of the test can be accounted for by the presence of initial stress. If the beam were under initial stress, an apparent compression, as indicated by the micrometer, might be only a release of tension. Thus a fiber which apparently suffers no deformation under loading might nevertheless be under stress.

After the concrete in the lower side of the beam has cracked, the micrometer readings are probably not of much value in determining the stress in the steel, which would then be variable through the gage length, being large in the vicinity of the cracks, and smaller where the concrete remains intact. Deductions as to the stress in the steel based on micrometer measurements, are thus apparently marred in the earlier stages of the loading by initial stress, and in the later stages by the presence of cracks.

CONCLUSIONS.

The curves of unit deformations seem to indicate that a section plane before bending practically remains a plane after bending, the greatest distortion occurring under the higher loads.

The curves of unit stresses indicate that within the working compressive stresses ordinarily used in practice, a straight-line variation very nearly represents the actual distribution, the tensile strength of the concrete playing but a small part in influencing the value of the resisting moment.

Referring to Table II, it is seen that the measured maximum compressive stresses, approaching practical values, accord fairly well with those obtained by the theory of straight-line distribution with no tension in the concrete, using 30,000,000 for the modulus of steel and 2,000,000 for that of concrete, which are the values recommended for use by the Joint Committee on Concrete and Reinforced Concrete in 1909.

It is hoped that means will be devised for measuring the amount of initial stress in reinforced concrete, for it is apparent that this stress might be quite large.

COMPARISON OF PLAIN CONCRETE IN TENSION AND COMPRESSION.

Tables III, IV, and V present an interesting comparison of concrete in tension and compression. In but few instances does the modulus of elasticity in tension exceed that in compression, the average values of the tension modulus varying approximately from 56 to 82 per cent. of the compression modulus. The tensile strength varies from 6 to 9 per cent. of the compressive strength.

Referring to the tension curves shown in Figs. 2, 4, 6, 8, and 10, it will be seen that a straight inclined line in most cases nearly averages the plotted points, unlike the case of compression, showing a very small amount of deformation under the maximum loads.

As before stated, difficulty was experienced in measuring the extremely small elongations of the concrete, and for this reason it would have been of advantage either to have used a compressometer reading finer than one ten-thousandth of an inch, or to have doubled the gage length, preferably the latter.

THE PAINTING OF CEMENT AND CONCRETE STRUCTURES.

By Charles Macnichol.

Cement and concrete construction has recently assumed great proportions in the building world. Its great use in the construction of residences, and other structures which formerly were built of wood, makes it imperative to develop some means of giving it a finished appearance. It is, moreover, not complete in appearance until made acceptable to the trained eye of the master painter.

This is a problem for the paint chemist to study from every standpoint, and it is his duty to work out a paint coating that will be permanent and satisfactory for general use. The paint manufacturers, civil and chemical engineers, and the authorities of the cement industry are all applying themselves to the solution of he problem, but candor compels the statement that their efforts have not kept pace with the requirements for practical use.

These requirements demand direct treatment of the freshly built cement surfaces, so as to adapt them to receive the materials which the paint trade is familiar with and which are in common use. Numerous methods have been tried for years by the painters. Their failure in most cases, however, is due to their lack of knowledge of the oil-destroying property of the alkali in the cement and of the value of such chemicals as science has given us for the neutralization of these alkalies.

For the decoration of cement structures, we are without a paint combining the requisite properties, which may be summarized as follows:

1. Reasonable permanency of the painted surface.
2. Freedom from chemical action on the oils.
3. Assurance that the tints or colors will remain unimpaired.

The method that has given the nearest approach to fulfilling these requirements, I desire to submit as a result of years of prac-

tical experience; I have used it in business for years with success, and it has proved not only practical in application but successful in results, combining as it does freedom from danger to those handling it, simplicity in preparation and application, and reasonableness in price.

The method consists in treating the cement surfaces with a solution of zinc sulphate and water, equal parts by weight, applied with an ordinary bristle brush after the cement is dry. If the one precaution is observed, of allowing from 48 to 72 hours as a drying period, this treatment will render a cement wall as safe to paint as an ordinary plaster wall.

I offer this as a result of actual use, disclaiming any knowledge of theoretical chemistry as the basis of this discovery. In giving such publicity to my method, however, I have availed myself of the endorsement of one of the most eminent research chemists of the United States, namely, Dr. Allerton S. Cushman, Chemist in Charge of Physical and Chemical Investigations, Office of Public Roads, Washington, D. C. When I became anxious to know why the zinc sulphate was so valuable, I wrote to Dr. Cushman and propounded the question: "What chemical action takes place on a cement surface when a solution of zinc sulphate has been applied?" I attach his reply thereto:

In reply to your request, I beg to advise you as follows: In regard to the scheme for painting concrete work with a solution of zinc sulphate in order to make the surface hold a paint coating, it is my belief that zinc sulphate is very well adapted for this purpose, owing to the fact that when zinc sulphate is brought into contact with calcium hydroxide (hydrated lime), a chemical reaction takes place which results in the formation of calcium sulphate (gypsum) and zinc hydroxide (hydrated oxide of zinc).

It is apparent from this that after the surface has become thoroughly dry again, it will contain within its pores a mixture of gypsum and zinc oxide; these materials have no bad influence on linseed oil and, in fact, are frequently used as paint pigments.

The reason why some such treatment should be necessary before applying a paint coating to the surface of concrete must be apparent to every one. When Portland cement sets, a certain amount of lime is set free in a hydrated condition as calcium hydroxide. This is a strong alkali, and tends to saponify the oil in the paint coating and thus destroy it. The work done by the application of zinc sulphate is to destroy this alkalinity, and change the calcium hydroxide into a mixture of calcium sulphate and zinc oxide.

I do not know of anything that would answer this purpose better than zinc sulphate.

Yours very truly,
(Signed) ALLERTON S. CUSHMAN.

A secondary reaction which takes place, and a very important one to the painter, is the filling of the pores of the cement, which has the action of preventing suction, thus keeping the oil paints applied from penetrating too deeply into the cement.

In conclusion the writer again calls your attention to the fact that he is not a chemist, but a master painter, and if, in his wanderings around the outskirts of chemistry, he has found a simple method of admittance, he is glad to avail himself of this opportunity to spread the information broadcast, for the edification of the craft at large.

DISCUSSION.

Mr. H. A. Gardner.

MR. H. A. GARDNER.—I have applied Mr. Macnichol's method to surfaces in delicate colors, such as Prussian blues, greens, reds and yellows. In every case I have obtained good results as shown after a year's test.

Mr. Dewar.

MR. JOHN DEWAR.—Having heard of the Macnichol process of treating cement surfaces with a solution of zinc sulphate and water so that paint could be applied with perfect safety to such surfaces, I tried it out during the past year. The results were entirely satisfactory, and proved the claim of Mr. Macnichol for its usefulness as a protector of paints applied to cement surfaces. One large operation which I had was of such a character that I am quite sure that without its use the results would have been very unsatisfactory. From my personal experience with the process I can heartily recommend it.

The President.

THE PRESIDENT.—Mr. Macnichol might perhaps add to the interest of his paper if he would tell us how he came to think of zinc sulphate.

Mr. Macnichol.

MR. CHARLES MACNICHOL.—I started at first with blue vitriol. One day I happened to run across an old English magazine of the year 1837 in the Congressional Library; I do not remember the title of the magazine. I saw there a reference to some one having used what they called paint-lining paper. That was before the days of paperhanging. It was stated that it was necessary to coat the fresh plaster with vitriol; and knowing something of the difficulties of fresh plaster, or "hot plaster," as we term it in the trade, and that they were similar to the difficulties encountered with cement and concrete, the idea occurred to me to apply it to cement. I found it was practical, and after beginning with the use of blue vitriol in that way, I finally came to use sulphate of zinc.

Mr. Cushman.

MR. A. S. CUSHMAN.—I should like to state that I have made a great many experiments, mixing soluble sulphates with Portland cement mortars, and the result that I obtained in nearly every case showed a decided weakening in the tensile strength of

Mr. Cushman. the briquettes when the zinc sulphate is added to the mortar before it is spread on the wall. It occurred to me that if zinc sulphate has a good effect on a surface, possibly it would be even better if it could be mixed into the mortar before the wall is laid, but my experience so far with the use of zinc sulphate has been that it is apt to cause crumbling of concrete or mortar. I must say, however, that in using ferrous sulphate with the same idea I have obtained just as good strength as though plain water had been used in the tempering. In two series of briquettes that I have tested, at the end of 28 days in water I got higher results than when plain water was used for tempering. I cannot at present explain these results.

A Member. A MEMBER.—I should like to ask what effect the use of this process has on the appearance of the surface.

Mr. Macnichol. MR. MACNICHOL.—It has very little effect on it; it never affects any tints that are put on it. I have used it as a filler for cement and have then coated the cement surface with kalsomine in very delicate hues of blues, yellows and pinks, and I find that it has no effect at all on the color. It changes the natural color of the cement very little, merely showing a little white powder on the surface.

SOME EXPOSURE TESTS OF STRUCTURAL-STEEL COATINGS.

By C. M. Chapman.

About three and a half years ago Westinghouse, Church, Kerr and Company exposed to the weather, on the roof of the building occupied by them at the southern extremity of Manhattan, 24 small steel plates, each coated with a so-called steel-preservative paint. The great difference soon noted in the protective value of these paints led to the testing of other paints and coatings, until some 1,600 plates have now been exposed, painted with 530 different coatings submitted by 271 manufacturers or dealers.

The results obtained to date are more or less interesting and valuable, according to the conclusions which may be drawn from them. Herein we will state only the facts; the conclusions may be drawn by each of you for himself.

The method employed in most of these tests was as follows: Small samples of the ready-mixed paints were submitted by the manufacturer or dealer, together with a statement of the principal ingredients entering into their manufacture. Each paint was applied to two mild-steel plates of about No. 16 gage, 2 ins. wide and 6 ins. long, which had first been well cleaned of oil and foreign matter by rubbing with a cloth saturated with benzine. Each plate had its number plainly stamped in one corner. One plate was given one coat and the other two coats. Care was taken to give a uniform full coat to both sides and all edges of the plates. All painting was done indoors and by the same person. About five days were allowed between coats for drying. After the second coat had dried, the plates were fastened to boards with galvanized iron tacks and exposed on the roof at an angle of 45°, facing south. Fig. 1* shows some of these plates on the boards as they are now exposed on the roof.

On the day the plates were exposed, scratch marks were made with a sharp instrument across two opposite corners of each plate. These scratch marks cut through the paint film, leaving bright metal exposed so that rust could and did start immediately

*Acknowledgment is hereby made to *The Iron Age* for the cuts used in this paper.—Ed.

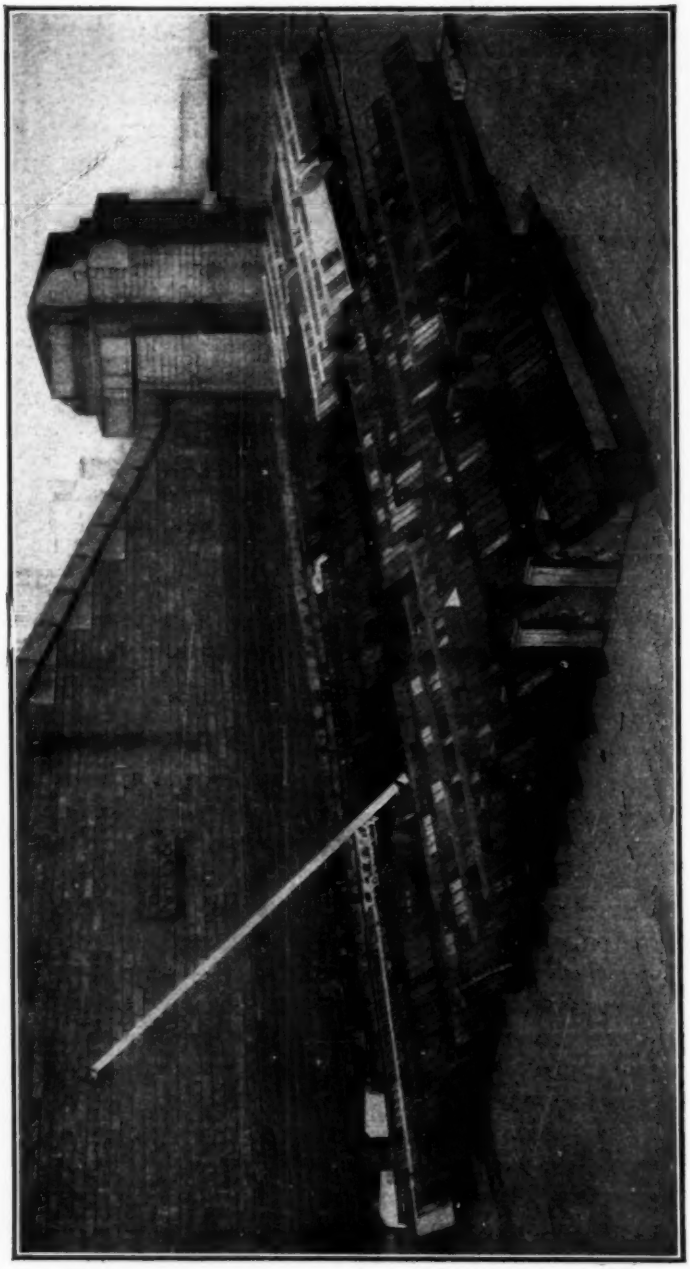


FIG. 1.—Exposure Tests of Structural-Steel Paints.

along these lines. At regular intervals after exposure each plate was examined and a record made of its condition. The one quality which was being sought, and the prime factor which entered into the rating of the paints, was protection against rust.

An arbitrary scale of ratings was adopted, based on the amount of rust apparent on the plate. Until some small spot of rust appeared the plate was rated at 100 per cent., except cases of fading, alligatoring, bad chalking, etc., without any apparent rust, which were rated at 97 per cent. When one small spot of rust, the size of a pinhead, appeared, the plate was rated at 90 per cent. When several such spots or one larger spot of rust appeared, the plate was rated at 85 per cent. When the sum of the areas of the rust spots totaled an area of about one quarter-inch square, or one-sixteenth of a square inch, the plate was rated at 80 per cent.; when a half-inch square, or one-fourth of a square inch, at 75 per cent. When the combined area of rust spots totaled about one square inch the plate was rated at 70 per cent., and so on down the scale, zero rating indicating that the plate was entirely rusted on the exposed side. Fig. 2 shows a series of plates in various stages of the progress of the rust from 100 per cent. to zero. Examinations were made and results recorded at the end of two weeks, four weeks, six weeks, twelve weeks, and every three months thereafter.

The scratch marks across the corners of the plates developed some interesting results by showing the relative resistance offered by the various coatings to the spread of the rust, which started where the bright metal was exposed. Fig. 3 shows clearly two rather extreme cases. In one case the coating has failed at many points and the plate has rusted at each of these weak spots, but the coating has not allowed the rust to progress under it, and therefore the rust spots are small and the rust at the scratch mark is still confined within narrow limits. Should this paint be called a good inhibitor and a poor excluder? The other case is that of a paint which has allowed the rust to spread rapidly where it once got a start at the scratch marks, but has not allowed a single spot of rust to start on any other portion of the plate. Is not this evidence of a poor inhibitor but a good excluder? Both of these plates have been exposed the same length of time.

Another interesting and somewhat curious fact has been

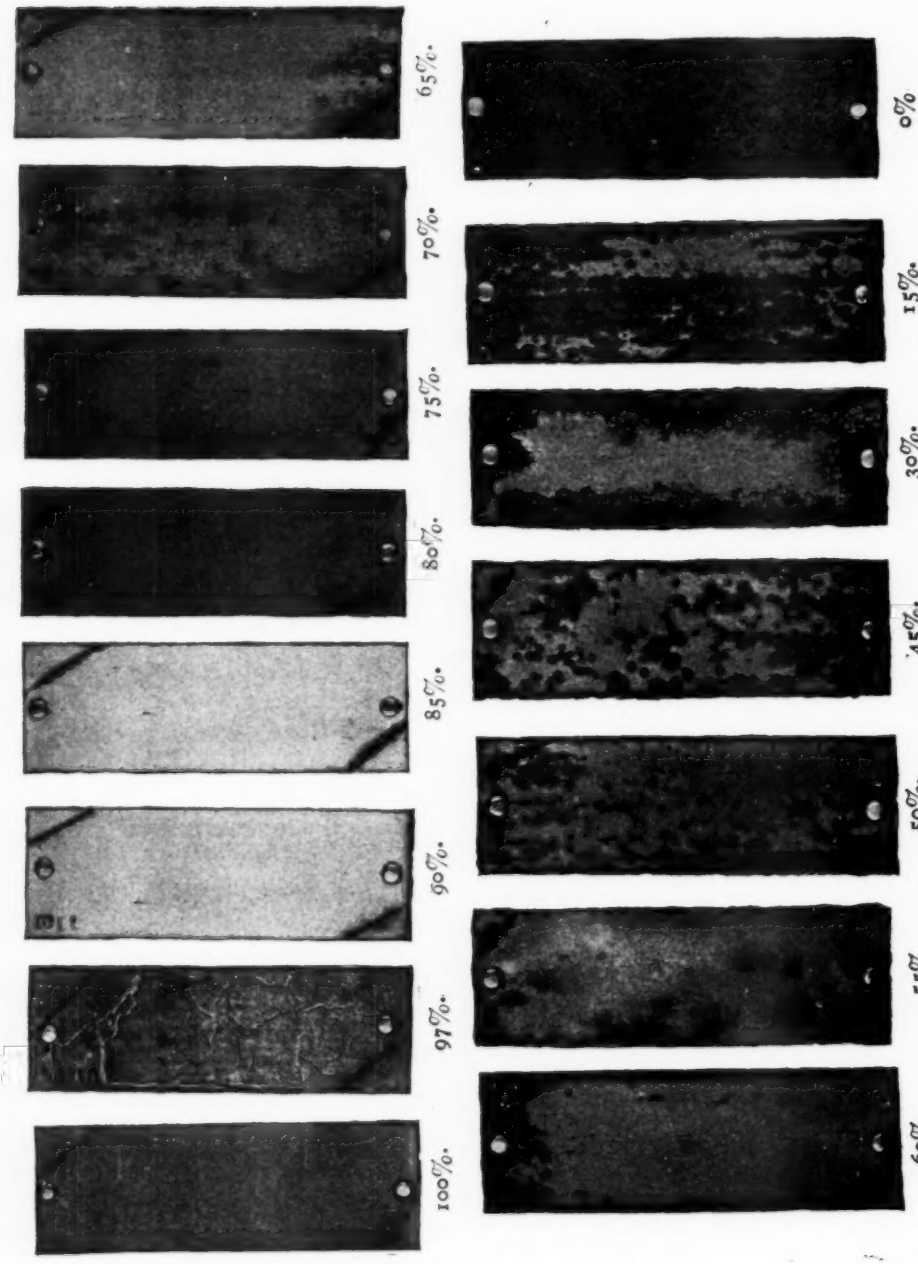


FIG. 2.—Progressive Stages of Corrosion and Corresponding Ratings.

noted in these tests. It is that the various classes of pigments fail in characteristic manners. A plate coated with a graphite paint does not rust in the same manner as one coated with red lead or an iron oxide. This difference is illustrated in Fig. 4, which shows the characteristic failures of four classes of paints: carbon, graphite, iron oxide, and red lead.

As the tests plates were exposed from time to time throughout the year in lots of about two hundred, it would not be fair to com-

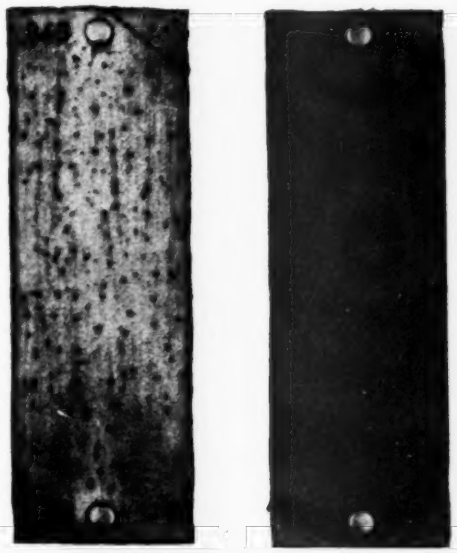


FIG. 3.—Spread of Corrosion from Scratch Marks.

pare the three or six months' rating of a paint exposed in June, with the corresponding rating of one exposed in November, after the one had been subjected to warm, dry weather and the other to an equal period of cold, rain and snow. For this reason, the one-year and two-year ratings are compared in all cases, so that all have been exposed to the four seasons in succession one or more times.

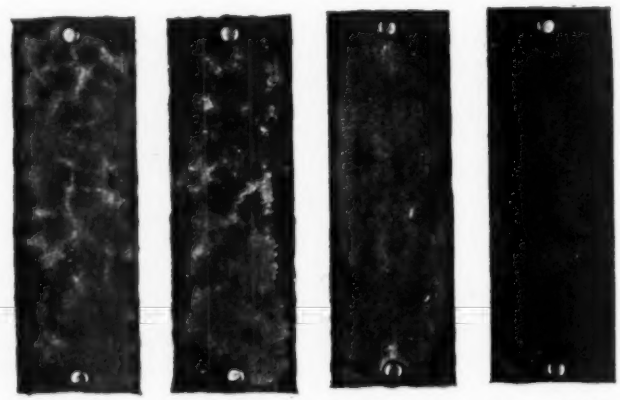
As noted above, each manufacturer was asked to state the principal ingredients in his paint, and on the basis of these statements the samples were classified into groups depending upon the chief pigment, or, in the absence of pigments, upon the vehicle. In this way the paints were divided as follows:

Carbons.—In this class are grouped the natural and artificial carbons, except graphite.

Graphites.—This class contains both the natural and artificial graphites.

Iron Oxides.—These include both the natural and artificial pigments, some of which were received in paste or dry form and to which pure linseed oil was added in our laboratory.

Red Leads.—This class includes both the straight red lead and oil, mixed in the laboratory shortly before applying, and the ready-mixed red lead paints, which contain considerable per-



Carbon. Graphite. Red Lead. Iron Oxide.

FIG. 4.

centages of other pigments to keep the lead in suspension. These red leads had no other coating over them.

Red Lead Primers.—These include those tests in which the first coat was a red lead paint, either ready-mixed or straight red lead and oil, while the second coat was of some other class. Of course, no one-coat tests could be made in this way. The second coats in this class were of widely different varieties.

White Leads.—This class is rather surprisingly small and is made up largely of paints mixed from the paste in our own laboratory.

Zinc Oxides.—Few makers put out a zinc oxide paint for structural steel.

Mineral Hydrocarbons without Pigments.—This class is

composed of paints made of the various kinds of tars and tarry refuse, and the various minerals of an asphaltic nature, gilsonite, elaterite, etc., but without any pigments added to them. They form one of the more numerous groups and as a rule are much

TABLE I.—RESULTS OF EXPOSURE TESTS OF STRUCTURAL-STEEL PLATES.

Class.	One Year Exposure.				Two Years' Exposure.			
	One Coat.		Two Coats.		One Coat.		Two Coats.	
	No. of Tests.	Average Rating, per cent.	No. of Tests.	Average Rating, per cent.	No. of Tests.	Average Rating, per cent.	No. of Tests.	Average Rating, per cent.
Carbons	65	21	54	70	34	2	36	46
Graphites	67	18	56	66	42	3	43	45
Iron oxides	74	35	71	69	52	10	52	46
Red leads	50	58	39	77	19	16	20	61
Red lead primers	0	....	43	75	0	....	14	56
White leads	23	51	11	82	3	0	3	25
Zinc oxides	5	25	5	69	5	3	5	50
Mineral hydrocarbons without pigments	66	20	73	46	36	0	37	18
Mineral hydrocarbons with pigments	10	16	11	53	7	0	7	20
Vegetable hydrocarbons with and without pigments	13	19	13	57	3	0	3	5
Cements	7	36	7	46	1	0	1	0
Chromates	14	32	24	70	9	0	9	39
Vehicles	22	8	7	11	3	0	3	0
Miscellaneous	94	28	103	67	70	7	85	39

lower in price than the oil paints. They also form the class for which the greatest merit is usually claimed by the makers and agents.

Mineral Hydrocarbons with Pigments.—This class is made up of materials of the same character as the last but with various pigments added. For instance, a paint made of gas tar and iron oxide would fall in this class rather than in the iron-oxide class.

Vegetable Hydrocarbons with and without Pigments.—This class includes distillates and residual pitches of vegetable oils, etc. They are not numerous enough to be divided into two groups; hence those with and those without pigments are placed in the same class.

Cements.—Several manufacturers have acted upon the oft-published statement of the fact that Portland cement offers a protection to steel against rust and have put out a paint said to be made up largely of cement. These paints are here grouped in a class by themselves. As they have appeared in the market mostly within the past two years, only one of them has had a full two years' exposure.

Chromates.—Another effect of recent paint literature has been to cause the appearance of a number of paints said to contain chromates or chromic acid in some form. Some of these have appeared within the past year and no tests of those can be included in this paper.

Vehicles.—This class comprises the oils, varnishes, and transparent coatings which contain little or no pigment, but which are used more or less for the protection of steel.

Miscellaneous.—Into this class are grouped all the coatings which do not fall into one of the above groups or concerning which the maker refused proper information to enable the paint to be classified. Other subdivisions were made in our laboratory records, but they each contained so few representatives that they were all placed in this miscellaneous class for purposes of comparison in this paper.

In Table I is given a summary of the results obtained with each class of paints for one- and two-year exposures of one- and two-coat specimens. This table also gives in each case the number of tests which entered into each result.

DISCUSSION

MR. H. A. GARDNER (*by letter*).—The above tests as carried out by Mr. Chapman have extended over three years, and represent an effort to determine the relative efficiency of various commercial paints upon the market, as protectors of steel from rust. Mr. Gardner.

Although these tests may have indicated to some extent the relative values of the paints tested, they are of such a nature that no definite conclusions can be drawn regarding the properties of the pigments the paints are supposed to represent. For instance, the paints were nearly all submitted by manufacturers without full formula, only statements being made as to some of the ingredients in the paint. Those paints sent in as chromate paints and so classified may have contained anywhere from 1 to 99 per cent. of chromates, either of the water-inhibitive type, such as zinc chromate, or of the water-stimulative type, such as imperfectly washed lead chromate. Mr. Chapman's tables show that fifty-six chromate paints were tested, but when these paints were submitted, the art of manufacturing rust-inhibitive chromate paints was not developed to the extent that exists to-day, possibly only three real inhibitive chromate paints being on the market. The testing of such paints, without definite formula, and their classification into one group, is of course unfair, and leads only to confusion of results. The red lead paints, so-called, which were included in the tests, may have contained in a great many cases up to 50 per cent. of whiting, gypsum, or other pigments which are used by manufacturers to prevent the red lead from settling out or hardening in the can. The relative actions of red lead and of whiting upon iron and steel are entirely distinct; the red lead is a protector of steel and whiting the reverse, on account of its rapid chalking and disintegration. The carbon paints tested may also have contained other pigments, such as iron oxide, red lead, graphite, sublimed blue lead, etc.

The steel plates used for the test were 2 ins. wide and 6 ins. high, and small brushes were used for the application of the paint. Such a test would not, of course, be comparable to the

Mr. Gardner. testing of paints on large areas. The arbitrary method adopted by Mr. Chapman for arriving at the percentage rating of each paint, solely from the rust spots apparent, seems faulty, as those factors which he has practically not considered, such as alligatoring, chalking, fading, etc., are factors of the utmost importance in determining the value of a protective paint. A paint when applied to a large sheet of metal might show one or two rust spots in a small area about the size of the plates used by Mr. Chapman, and give perfect protection to the balance of the plate. Again, a plate might show a relatively good surface, with apparently no rust spots, but upon removal of the film there might be found a very deep layer of rust over the entire surface of the metal. This is almost invariably the case at the end of a short test, when gypsum or carbonaceous pigments are used.

The tacking of the plates to the exposure boards with galvanized iron tacks was unfortunate. The iron might be protected for a small area around the galvanized tacks, but local galvanic currents might be set up without this area, that would cause pitting and rusting not due to the paint itself, which was being tested.

Although no definite conclusions can be drawn from these tests, a careful charting of those paints which received the highest ratings on two-coat work for one-year and two-year exposures respectively, seems to indicate that the so-called water inhibitors, such as red leads and chromates, are of the most value for the protection of iron and steel. The absence of data, however, as to the real composition of the paints tested, makes it hazardous to draw any definite conclusions from these tests.

SUMMARY OF RESULTS OF TWO-COAT WORK.

	One-Year Exposure.	Two-year Exposure.
Red lead paints	77	61 per cent.
Red lead primers	75	56 " "
Chromate paints	70	39 " "
Carbon paints	70	46 " "
White lead paints	82	25 " "

Mr. Chapman. MR. C. M. CHAPMAN (*by letter*).—In replying to the remarks of Mr. Gardner, it may be pointed out that while what is said about the chromate paints being of unknown composition is quite

Mr. Chapman.

true, yet the samples tested represent just the kind of paints you or I would get if we went into the market and bought a chromate paint; they represent the best paints of this character that the makers knew how to produce at the time these samples were submitted. And the tests here reported represent the relative value of the manufactured chromate paints as compared with the laboratory products on our test fences. The same remarks apply to the other classes, the red leads, carbons, graphites, etc. The tests represent the average value of the different groups as they are obtainable in the open market. These tests are not reported in order to teach the manufacturer how to make his paint, but rather to show the consumer what service he is likely to get from the various kinds of trade paints sold in the market. As the average buyer does not analyze the paint he buys, he is not interested in exact composition.

The plates used in these tests were small, and 1-in. badger hair brushes were used, and without further information than this it would be unwise to compare such small tests with others much larger. But the fact remains that these small tests do very closely check with the larger ones, and they check with themselves, as has been demonstrated by frequent duplication of tests; and still further, they check with the large-scale field tests which have been duplicated on these little 2- by 6-in. plates.

The arbitrary scale of ratings is of course not directly comparable with any other scale of ratings. It indicates very clearly to one familiar with it just how good a protector against visible corrosion the particular paint is. The following experiment, which has been repeated several times, indicates that the scale is at least fairly indicative: the scale of ratings was explained to several different observers, and then each examined and rated a hundred or more test plates. The almost exact agreement between the independent observers lead to the adoption of the scale.

While alligatoring, chalking, fading, etc., are undoubtedly factors of great importance in determining the value of a paint, yet the one factor which proves whether a paint is a good or bad protector of iron against rust is whether or not rust is present on iron coated with that paint. However badly a paint may fade, chalk, or alligator, if less rust develops on iron painted with that paint than develops when another paint is used, then choose the

Mr. Chapman. former paint every time, *provided it is protection against rust you desire.*

The criticism that "a plate might show a relatively good surface, with apparently no rust spots, but upon removal of the film there might be found a very deep layer of rust over the entire surface of the metal" applies with as great force to the large plate test as to the small plate test. The tests reported in this paper, however, have in this particular respect an advantage over some of the test fence plates at Atlantic City, in that they are all very uniformly smooth to start with and any development of heavy rust under the film roughens the surface at once. In the case of a few of the larger plates, there was some roughness of the plates which later could not be positively distinguished from roughness due to rust under the paint film. It seems that it would be wise in selecting large plates to be sure to have all surfaces quite smooth before painting.

As to the use of galvanized tacks for attaching the plates to the boards, a careful examination of the large number of plates now exposed fails to show any such effect as it is pointed out might occur.

These tests are not of the chemical laboratory type but rather of the paint users "back-fence" variety, except that they were carefully and accurately prepared by persons experienced in experimental research; and the accuracy with which they check among themselves and with larger tests having nearly the same time exposure is the best indication of their value.

We do not wish to be misunderstood as advocating the use of small plates rather than large ones in making paint tests, but if a wee small plate in a bottle containing water and a pigment can give results from which "inferences" at least may be drawn, then why may not the same plate exposed to the atmosphere with the same pigment on it give information worth knowing?

As stated in the paper, the results obtained are more or less interesting and valuable according to the conclusions which may be drawn from them. To those who cannot draw any conclusion or gather any useful information, the results are quite useless and uninteresting.

Mr. Cushman. MR. A. S. CUSHMAN (*by letter*).—The method devised by Mr. Chapman of recording the results of exposure tests is most

interesting and is a valuable contribution to the subject. It is to be regretted that at the time this inclusive series of tests was begun, the recent theories of inhibition had not been developed. As the matter stands it does not appear that these tests can be considered as supplying data either in support or contravention of the inhibitive theory. On the other hand the results obtained have undoubtedly served a useful purpose, as within their limitations they point out the great differences that exist in the suitability and efficiency of various protective coatings offered by manufacturers. In the opinion of the writer the test plates should have been larger. It is probable that if similar tests could now be carried on with larger plates and in the light of recent knowledge and experience, the scientific principles which should govern the design of protective coatings could be definitely established. A good beginning has been made in the test panels at Atlantic City, but the problem is of such importance that it warrants further systematic and scientific development. **Mr. Cushman**

Mr. Chapman's suggestion that some of his results may possibly be explained on the theory that some paint coatings depend on their inhibitive value and others on their excluding power, is in accord with the observations of a number of other investigators. Mr. Chapman has clearly brought out the fact that paint coatings containing various classes of pigments fail in characteristic manners. The stimulating effects produced by pigments which though pure and neutral in themselves are good conductors of electricity of the first class, are quite different from those produced by pigments which contain soluble impurities or are themselves to some degree soluble in water. Pigments which contain chromates or other more or less soluble compounds which render the surface of iron passive, check or inhibit corrosion. The problem is therefore complex, as in many composite paints we may expect to find all these elements present at one and the same time. Only a thorough knowledge of what the paint composition contains, with the fullest details of the process of manufacture, will permit of a complete interpretation of the results of exposure tests.

VERMILION PAINT FOR RAILWAY SIGNALS: RESULTS OF AN INVESTIGATION.

By Robert Job.

In the painting of railway signals, the common practice some years ago was to use the so-called English or Chinese vermilion, the red sulphide of mercury. This pigment was mixed or ground with linseed oil, and while the paint was fresh, the coating gave a brilliant and striking signal. It was found, however, as is well known, that on exposure to light and sulphur fumes, a gradual darkening took place, due to the chemical reduction of the pigment or the formation of the black sulphide. Under favorable conditions a fair life was obtained, but in unfavorable surroundings, darkening or blackening took place rapidly, and repainting became necessary after relatively short exposure. Unfortunately, too, the price of the material was extremely high and out of all proportion to the durability obtained.

Owing to these reasons, strenuous efforts were made to secure a substitute equally brilliant at the outset, but having the advantages of greater serviceability, with lower initial cost. Experiment was made with various inorganic pigments, such as American vermilion (basic lead chromate), mineral orange, and other substances, but they were found to be unsatisfactory in one characteristic or another, and did not have the requisite brightness of color or else did not retain the color satisfactorily on exposure.

The field of organic reds had been largely developed and thorough trials were made of a number which appeared promising. It was found, as a result of these service tests, that many of these reds, such as eosine, were extremely fugitive and faded very rapidly on exposure; others gave fairly satisfactory results. The para-diazo reds were the most permanent and generally satisfactory, and retained their brightness for considerable periods of time, even under unfavorable surroundings. The shade of this red was not as bright and striking as desired, though it was improved by the addition of mineral orange (Pb_3O_4), but the latter material, when

present in any considerable proportion, caused blackening, due to the formation of lead sulphide. Good results were obtained, however, when the proportion of mineral orange did not exceed 10 per cent. Other diazitized and developed aniline reds have recently been brought out, and exposure tests of these are now under way.

The para-diazo red was precipitated upon various bases, but in service tests barium sulphate was found the most satisfactory. Paints prepared with varying proportions of para-diazo red precipitated upon barium sulphate, were tested carefully by exposure, and it was found desirable to have present not less than 20 per cent. of the red in order to ensure a good degree of permanency, with little evidence of fading after a year's service.

In order to hold shipments to the desired standard, the following specifications were adopted:

SPECIFICATIONS FOR SIGNAL RED PAINT.

1. *Proportions.*—Signal red paint will be bought in semi-paste form, consisting solely of oil and pigment, in proportions close to 30 per cent. by weight of oil, and 70 per cent. by weight of pigment.

2. *Composition.*—The material desired consists of about 23 per cent. of para-diazo red precipitated upon barium sulphate ("blanc fixé"), with not more than 10 per cent. of mineral orange.

3. *Fineness.*—Shipments must be free from lumps, and from hard settlings upon the bottom of the packages: and no feeling of grittiness must be apparent upon rubbing up the paste with oil with a spatula upon glass.

4. *Shade.*—Samples of the desired shade will be furnished upon application to the purchasing agent, and shipments will be required to conform closely to this standard.

5. *Conditions.*—Shipments will not be accepted,

(1) Which contain less than 28 per cent. or more than 32 per cent. by weight of pure raw linseed oil, any oil not pure raw linseed, or more than 2 per cent. of matter volatile at 212° F.

(2) Which contain in the pigment less than 20 per cent. by weight of para-diazo red; any organic material other than para-diazo red; more than 10 per cent. by weight of mineral orange, figured as Pb_3O_4; any carbonate of lime, sulphate of lime, or any

base other than barium sulphate ("blanc fixé"); or if the para-diazo red is not precipitated upon the base.

(3) Which vary to any extent from the standard shade; do not meet fineness requirements; are so stiff when received that they will not readily mix for spreading; or which when thinned down ready for use, settle to a hard mass at the bottom of the can on standing over night.

ANOTHER SOLUBILITY TEST ON PROTECTIVE COATINGS.

By G. W. Thompson.

At the meeting of the Society in 1908 I presented a paper on "Certain Solubility Tests on Protective Coatings."* It has long been the belief of the writer that solubility affects very considerably the durability of protective coatings, and that tests should be conducted with all known solvents as promising to give information of great value.

The test described in this paper relates to the solubility of protective coatings in water. It has long been noted that certain protective coatings tended to wash, and that under certain conditions soluble compounds would come to the surface and form a gummy scum on the surface. Cases have been noted where the soluble compounds formed bitter and astringent solutions. Sometimes these soluble compounds would appear as miniature stalactites on the ceilings of porches.

The test which I will describe refers to two pigments which we will designate as *a* and *b*. Six white-pine boards 30 ins. long, 10 ins. wide, and $\frac{7}{8}$ in. thick were primed with a mixture of Pigment *a* and linseed oil, one-third boiled and two-thirds raw. When these priming coats were dry, mixtures of paint were prepared on approximately the same volume basis—that is, each paint contained the same actual volume of pigment and vehicle. The oil used was the same as for the priming coat and contained no resinous compounds.

The pigment on Board No. 1 consisted of 100 per cent. Pigment *a*.
The pigment on Board No. 2 consisted of 80 per cent. Pigment *a* and 20 per cent. Pigment *b*.
The pigment on Board No. 3 consisted of 60 per cent. Pigment *a* and 40 per cent. Pigment *b*.
The pigment on Board No. 4 consisted of 40 per cent. Pigment *a* and 60 per cent. Pigment *b*.
The pigment on Board No. 5 consisted of 20 per cent. Pigment *a* and 80 per cent. Pigment *b*.
The pigment on Board No. 6 consisted of 100 per cent. Pigment *b*.

* *Proceedings*, 1908, Vol. VIII, p. 601.

The paint was applied in two coats, spread at the uniform rate of 1,200 sq. ft. to the gallon. The painting of these boards was done between the dates of October 16 and 22, 1909. When the paint was thoroughly dry, the boards were placed in a rack about 8 ins. apart, as shown in Fig. 1. The rack was covered

FIG. 1.

with cheesecloth to keep away the dust as far as practicable, and every working-day—morning and evening—the under surfaces were sprayed with distilled water by an atomizer. Only so much water was sprayed on the boards as would remain there, and no dripping was allowed to occur. The theory on which this test was conducted was that this constant spraying would gradually draw toward the surface of the paint any soluble compounds contained

in it, and ultimately, if soluble compounds were formed they would show as a scum on the surface of the paint. For the first month or two nothing developed; then on all of the boards containing Pigment *b* the scum appeared, and has gradually increased in amount to date. This scum is a brownish looking mass and appears to be composed of Pigment *b* in combination with some organic substance. The formation of this organic compound of Pigment *b* would seem to account in some cases for the washing and streaking of paint.

This paper is presented with the idea that investigators will take this subject up and carry it further in an endeavor to discover just how the soluble compound is formed and how its formation can be prevented. The writer does not care to mention in this paper the names of Pigments *a* and *b*, although he would have no objection to stating what they are to any person interested. His reasons for not disclosing in this paper these names is that there would arise the danger of some one condemning Pigment *b* on this one test. The value of a pigment is not determined by any one property, nor should it be condemned for any one fault; all the qualities of a pigment must be considered together in estimating its worth.

These tests are being carried further on different kinds of wood, and on steel and galvanized iron, with the hope of being able to determine whether the formation of soluble compounds depends in any way on the surface painted. This test is offered as a suggestion to those who are disposed to investigate paints along this line.

THE DETERMINATION OF SOLUBLE BITUMEN.

By Prévost Hubbard and C. S. Reeve.

One of the fundamental tests in the examination of bituminous materials is undoubtedly the determination of soluble bitumen, or total bitumen as it is sometimes called; and yet in common with most other tests of such materials, important variations exist in the methods adopted by different analysts. Owing to the variety of materials which are classed as bitumen and to a diversity of opinion as to the definition of the term, this subject is a difficult one to handle in a satisfactory manner, and many analysts have adopted the method of reporting their results merely as the solubility of the material examined in a given solvent. This is perhaps the wisest procedure at present, and will be adhered to in this paper. With the hope of placing this matter upon a more rational basis, it is the authors' present purpose to open a general discussion of the subject by the presentation and brief consideration of data which they have so far secured.

The determination of soluble bitumen is employed mainly for the purpose of ascertaining what percentage of material is held in suspension as inert matter in so far as binding value is concerned. Such products are usually divided into two classes, organic and inorganic, and so reported, the separation being accomplished by igniting the residue obtained until all organic matter has been burned off. The organic matter is often called free carbon, especially in the case of tars, although there are many reasons for thinking that free carbon constitutes only a portion of this substance.

Without entering into a discussion as to what materials should and should not be classed as bitumens, it may be said that in this paper the term is made to include all organic substances commonly known as tars, mineral oils, the commercial residues obtained from each (known as pitches and artificial asphalts), native asphalts, and other solid native organic products composed mainly of hydrocarbons soluble in carbon bisulphide. In view of the variety of substances which are included under this

term, and the fact that mixtures of any two or more may be encountered as commercial products, it is most essential that a method of determining soluble bitumen be selected which is applicable to all or to the greatest number of materials. Accuracy, ease of manipulation, time consumed, and cost are also important factors to be considered, and have been constantly borne in mind by the authors in the work here described.

In selecting a solvent for our investigations, we noted that carbon bisulphide, chloroform, benzol, toluol, and turpentine have been used for the determination of total bitumen, and had time permitted it would have no doubt proven interesting to have shown correlated results with the use of each of these materials. As such volume of work would have precluded the possibility of our being able to present these data for discussion at this time, we aimed to select two solvents that would prove scientifically, as well as commercially applicable, and therefore adopted C. P. carbon bisulphide (Baker and Adamson) and commercial 90-per cent. benzol, boiling point 80.5° C. We appreciated the fact that chloroform is preferred by some chemists for the reason that in certain cases it exhibits a slightly greater solvent action than carbon bisulphide, but the results as a rule are so slightly different that we doubt its coming into general use on account of its much higher cost. The same objection holds for the use of C. P. benzol, which would no doubt have given more satisfactory results than were obtained through our use of the commercial material. Turpentine was not considered on account of the difficulty in obtaining a pure product of definite composition.

Having decided upon the solvents, it was our object to apply them in such manner as would be typical of the various methods now in general use among chemists engaged in bitumen work, to compare the results obtained, and possibly to recommend or evolve a method that would give a maximum degree of accuracy consistent with a proper economy of time. Consideration was given to the fact that there is a division of opinion among various operators as to the merits of hot or cold solvents, while with some the different forms of extractors appear to be preferred. For the purpose of meeting these conditions, the following general methods of procedure were adopted, using from 1.75 to 2 grams of the material to be analyzed in each case.

Extractor Method.—For the purpose of our investigation, the Wiley extractor was selected as embodying the general principles of most of the other types. This form of apparatus may be briefly described as consisting of a glass tube 9 ins. long by 2 ins. in diameter, shaped like a large test tube, and having a metal condenser which is attached to the cover and extends downward through the upper half of the tube. The sample, which has been weighed in the cone of a tared filter paper, is suspended in a bottomless porcelain receptacle from the apex of the condenser, and the solvent is heated in the bottom of the tube.

A few preliminary tests were made on filter papers of different make and size, single and double, after which the following method was adopted and used throughout the series reported below: Two 15-cm. C. S. & S. No. 575 hardened filters were folded lightly in the usual way, after which, taking their center point as the apex, they were rolled into narrow cones having a diameter of about 1 in. at the base. They were then counterpoised, and 1.75 to 2 grams of material was weighed in one of them. The paper containing the sample was placed inside of the counterpoise filter, the two were suspended in the receptacle of the extractor, and using about 35 cc. of solvent, the extraction was allowed to proceed until the washings came through practically clear. The papers were then removed from the apparatus, dried in a hot-air oven at 100° C., cooled, and weighed.

For the determination of insoluble inorganic matter it was necessary to accept the stated weight of ash for filter paper, which was deducted from the weight of the residue obtained upon ignition of the total insoluble material and the paper containing it.

Cold Method.—The sample was weighed in a 100-cc. Erlenmeyer flask, which had been previously tared. It was dissolved by the slow addition of 100 cc. of solvent, with constant twirling until the material was entirely broken up, after which the flask was placed in a dark closet for 17 hours. At the end of that time the solution was filtered through a fel of long-fiber amphibole asbestos, contained in a large platinum Gooch crucible, which had been previously ignited and weighed.

The form of Gooch crucible best adapted for such determinations, as designed by Richardson, has a capacity of 30 cc., is 4.4 cms. wide at the top, tapering to 3.6 cms. at the bottom, and 2.6 cms.

deep. The felt is made by beating up the asbestos in a mortar and suspending the finer particles in water. The suspended asbestos is poured into the crucible, which has in the meantime been placed in the vacuum filtering flask. As soon as the asbestos has somewhat settled, vacuum is applied and the felt deposited on the bottom of the crucible, which is then dried, ignited, cooled in a desiccator, and weighed. The prepared felt should be dense enough to barely transmit light when held so that the bottom of the crucible is between the eye and the source of light. If it is denser than this the filter is apt to clog, and if much thinner it is apt to let through the finer particles of insoluble material. With a little practice it is possible to prepare a uniform felt without difficulty.

All the insoluble matter was brought on the felt by scrubbing out the flask; a slight suction was applied when necessary, and the contents of the crucible were washed until the washings came through clear, or nearly so. The crucible and contents were dried in a hot-air oven at about 100° C., cooled, and weighed, after which any organic matter was burned off and the inorganic matter or ash determined by weighing again.

The flask was also dried and weighed in a number of cases in order to determine the possible error due to adhering material or variations in the weight of the flask under different atmospheric conditions. In the case of the asphalt and asphalt cement, the usual procedure of burning off the filtrate and recovering any ash therefrom was followed. The time of subsidence—17 hours—was selected as being sufficient and most convenient, for the reason that the samples could be dissolved and set away at 4 o'clock in the afternoon and be ready for filtration the following morning at 9 o'clock.

Hot Method.—The sample was weighed in a 100-cc. Erlenmeyer flask as before, and broken up by the addition of 50 cc. of solvent. The flask was then connected to a short spiral reflux condenser and placed over a steam bath, where the solution was maintained at its boiling point for 3 hours. The flask was then disconnected and the solution filtered, the procedure being exactly the same as in the cold method.

Bearing in mind the variety of materials which may be classed as bitumens, the authors endeavored to select six typical

commercial products which represent, through their different origins, three distinct classes of bitumens. We therefore made use of (1) a residual coal tar and (2) a residual water-gas tar; (3) a residual petroleum and (4) a blown residual petroleum; (5) a Bermudez asphaltic cement and (6) Bermudez asphalt. A general method of analysis that would prove applicable to such a series of materials should be accurate for the determination of soluble bitumen in practically all bituminous substances with the exception of Trinidad asphalt, which, owing to the peculiar nature of its fine material, has thus far been thought to require special treatment, and has therefore been purposely omitted from consideration in the present discussion.

The following tables are not only of interest in comparing the different methods, but the duplicate results show their probable limit of accuracy, as in every instance one set of determinations was made by each of the authors.

In Table I it will be noted that under the column headed "Insoluble Organic Matter," a number of negative quantities are

TABLE I.—EXTRACTOR METHOD.

Material.	Solvent.	Soluble bitumen, per cent.	Insoluble organic matter, per cent.	Insoluble inorganic matter, per cent.	Ash in filtrate, per cent.	Total	Residue from filtrate on Gooch, per cent.
Residual coal tar	Carbon bisulphide	81.01	18.90	0.09	....	100.00	....
		81.18	18.82	0.10	....	"	1.98
	90-per cent. benzol	61.08	38.76	0.16	....	"	0.98
		69.48	30.46	0.06	....	"	....
Residual water-gas tar	Carbon bisulphide	99.80	0.08	0.12	....	"	....
		99.94	—0.03	0.09	....	"	0.14
	90-per cent. benzol	99.54	0.38	0.08	....	"	....
		99.11	0.77	0.12	....	"	2.79
Residual petroleum	Carbon bisulphide	99.91	0.01	0.08	....	"	....
		100.17	—0.30	0.13	....	"	....
	90-per cent. benzol	100.35	—0.35	....	....	"	....
		100.10	—0.20	0.10	....	"	....
Blown petroleum residue	Carbon bisulphide	99.98	—0.10	0.12	....	"	....
		100.13	—0.24	0.11	....	"	....
	90-per cent. benzol	100.40	—0.40	....	....	"	....
		99.97	—0.11	0.14	....	"	....
Bermudez asphaltic cement	Carbon bisulphide	96.80	1.44	1.59	0.17	"	....
		96.58	1.56	1.72	0.14	"	....
	90-per cent. benzol	96.74	1.45	1.64	0.17	"	....
		96.74	1.41	1.67	0.18	"	....
Bermudez asphalt	Carbon bisulphide	95.61	2.29	1.92	0.18	"	....
		95.73	2.12	2.01	0.14	"	....
	90-per cent. benzol	95.44	2.29	2.09	0.18	"	....
		95.75	2.12	1.99	0.14	"	....

TABLE II.—FLASK METHOD, COLD; SEVENTEEN HOURS.

Material.	Solvent.	Soluble bitumen, per cent.	Insoluble organic matter, per cent.	Insoluble inorganic matter, per cent.	Ash in filtrate, per cent.	Total.	Residue in flask, per cent.
Residual coal tar	Carbon bisulphide	77.00	22.89	0.11	....	100.00	0.06
		77.09	22.79	0.12	....	"	0.05
	90-per cent. benzol	76.75	23.14	0.11	....	"	0.03
		74.00	25.93	0.07	....	"	....
Residual water-gas tar	Carbon bisulphide	98.48	1.43	0.09	....	"	0.00
		98.39	1.55	0.06	....	"	0.05
	90-per cent. benzol	94.85	5.03	0.12	....	"	0.00
		94.45	5.47	0.08	....	"	....
Residual petroleum	Carbon bisulphide	99.88	0.08	0.04	....	"	0.05
		99.86	0.11	0.03	....	"	....
	90-per cent. benzol	99.71	0.19	0.10	....	"	0.00
		99.79	0.13	0.08	....	"	0.02
Blown petroleum residue	Carbon bisulphide	99.78	0.16	0.06	....	"	0.02
		99.75	0.16	0.09	....	"	....
	90-per cent. benzol	99.60	0.29	0.11	....	"	0.01
		99.70	0.18	0.12	....	"	0.00
Bermudez asphaltic cement	Carbon bisulphide	96.72	1.45	1.54	0.29	"	0.05
		96.60	1.52	1.70	0.18	"	0.00
	90-per cent. benzol	96.41	1.84	1.67	0.08	"	0.00
		96.71	1.62	1.67	0.00	"	0.03
Bermudez asphalt	Carbon bisulphide	95.66	2.25	1.94	0.15	"	0.06
		95.65	2.32	2.02	0.01	"	0.03
	90-per cent. benzol	95.32	2.60	1.95	0.13	"	0.03
		95.40	2.40	2.04	0.16	"	0.07

found. This is due to the almost invariable passage of some of the insoluble matter through the first paper and its retention by the second. This, together with the fact that it is almost impossible to wash all of the bitumen out of the paper as evidenced by a residual stain, constitutes the chief objection to the extractor method. One other which may be mentioned, however, is that while the closest check results for the tars were obtained with the No. 575 C. S. & S. filter, this paper proved too close-grained for the asphaltic cement and asphalt, and soon filled to overflowing. Therefore B. & A. 9-cm. filters were used for these two samples. That insoluble organic matter passes through both filters in the case of the tars is shown by the results in the last column, which were obtained by immediately refiltering the filtrate from the extractor through a Gooch crucible fitted with an asbestos pad. In comparing the two solvents, it will be noted that carbon bisulphide is the most powerful for the tars, and that with it closer check results were obtained than with benzol. It may be added that in the extractor method that fraction of the benzol coming in contact with the bitumen is probably almost chemically pure.

In Table II it will be seen that very uniform results are obtained by the 17-hour cold method where carbon bisulphide is used as a solvent, the maximum variation in check results on soluble bitumen being under 0.2 per cent. Here again benzol is shown to be a less powerful solvent for the tars, and gives much poorer check results, the maximum variation being over 2 per cent. It was found that such variations occurred only when different lots of solvent were employed and not when two determinations were made from the same lot. Different lots of carbon bisulphide, however, gave as close checks as when the same lot was used. The error due to the small amount of residue remaining in the flask is seen to be negligible, not only in this table but also in Tables III and VII.

Table III shows that the hot flask method produces just as uniform results as the cold method, when carbon bisulphide is used, and here again 90-per cent. benzol is shown to be an inferior solvent. As compared with the cold method, the most noticeable

TABLE III.—FLASK METHOD, HOT; THREE HOURS.

Material.	Solvent.	Soluble bitumen, per cent.	Insoluble organic matter, per cent.	Insoluble inorganic matter, per cent.	Ash in filtrate, per cent.	Total.	Residue in flask, per cent.
Residual coal tar	Carbon bisulphide	78.76	21.15	0.09	....	100.00	0.05
		78.58	21.35	0.07	....	"	0.00
	90-per cent. benzol	75.20	24.73	0.07	....	"	0.00
		75.88	24.05	0.07	....	"	0.06
Residual water-gas tar	Carbon bisulphide	99.42	0.51	0.07	....	"	0.06
		99.46	0.44	0.10	....	"	0.00
	90-per cent. benzol	95.74	4.14	0.12	....	"	0.00
		95.73	4.15	0.12	....	"	0.03
Residual petroleum	Carbon bisulphide	99.85	0.12	0.03	....	"	0.03
		99.83	0.08	0.09	....	"	0.04
	90-per cent. benzol	99.73	0.21	0.06	....	"	0.00
		99.83	0.12	0.05	....	"	0.00
Blown petroleum residue	Carbon bisulphide	99.79	0.19	0.02	....	"	0.00
		99.76	0.17	0.07	....	"	0.05
	90-per cent. benzol	99.59	0.28	0.13	....	"	0.01
		99.70	0.19	0.11	....	"	0.03
Bermudez asphaltic cement	Carbon bisulphide	96.61	1.52	1.53	0.34	"	0.01
		96.69	1.46	1.57	0.28	"	0.01
	90-per cent. benzol	96.52	1.58	1.76	0.14	"	0.00
		96.64	1.51	1.61	0.24	"	0.04
Bermudez asphalt	Carbon bisulphide	95.63	2.25	1.92	0.02	"	0.00
		95.55	2.32	1.97	0.16	"	0.03
	90-per cent. benzol	95.33	2.44	2.09	0.14	"	0.00
		95.73	2.20	1.92	0.15	"	0.03

difference is the apparent increase in solubility of the various materials. Much of the insoluble organic matter is known to be in a very finely divided state, and as the method allows no oppor-

TABLE IV.—PERCENTAGE OF INSOLUBLE ORGANIC MATTER; REFILTRATION TESTS.

(Carbon Bisulphide.)

Material	Residual Coal Tar.	Residual Petroleum.	Bermudez Asphaltic Cement.
First filtration 17 hours	22.78	0.13	1.48
Refiltration 1 day later	0.32	0.07	0.11
" 2 days later	0.22	0.04	0.06
" 3 " "	0.23	0.08	0.07
" 4 " "	0.30	0.01	0.02
" 5 " "	0.16	0.12	0.05
" 14 " "	0.25	0.09	0.11
Total refiltrations 29 days	1.48	0.41	0.42
Grand total	24.26	0.54	1.90

tunity for quiet settlement of this residue, it was feared that a portion of the insoluble matter had passed through the filter. This seemed to be corroborated by the fact that, upon standing, the

TABLE V.—PERCENTAGE OF INSOLUBLE ORGANIC MATTER; REFILTRATION TESTS.

(Carbon Bisulphide.)

Material	Residual Coal Tar.	Residual Petroleum.	Bermudez Asphaltic Cement.
First filtration 1 hour	21.74 21.93	0.14	1.52
Refiltration 5 hours later	0.13 0.10	0.10	0.14
" 29 " "	0.43 0.42	0.05	0.09

filtrates from even the 17-hour cold tests invariably showed a deposit of insoluble matter in the bottom of the flask.

To determine how much this really amounted to, a series of refiltrations with carbon bisulphide were made on the residual coal tar, the residual petroleum, and the Bermudez asphaltic

cement, with results as shown in Table IV. All digestions were made in the dark. As the deposition continued beyond the period of three or four days, by which time complete sedimentation should have taken place, we were led to suspect that insoluble matter was actually being formed in the filtrate, possibly through a gradual reaction of the solvent with the bitumen.

Another series of refiltrations, starting with one-hour cold digestions shown in Table V, added to this suspicion, which was further confirmed by results given in Table VI, where coal tar, digested in cold carbon bisulphide for 52 hours and then boiled for one hour, shows a higher percentage of insoluble organic matter than either the one or six hours cold digestion. In this table it is also seen that the percentage of insoluble organic matter increases with the time of digestion, irrespective of settlement or agitation.

TABLE VI.—EFFECT OF DIGESTION OF RESIDUAL COAL TAR FOR DIFFERENT PERIODS IN CARBON BISULPHIDE.

Filtered After Standing.....	6 hours.	29 hours.	53 hours.	52 hours cold. 1 hour boiled.
Insoluble organic matter, per cent.....	22.56	23.15	23.49	22.74

To determine once and for all whether or not any insoluble organic matter had passed through the asbestos felt, a number of hanging drop specimens were prepared from both original solutions and filtrates for microscopic examination. When examined under high magnification, these specimens proved conclusively the following facts:

1. That while suspended organic matter could invariably be detected in the original solution, none was present in either the filtrates from the hot method or from the cold, even when the filtration was made immediately after solution.

2. That filtrates which showed no suspended material immediately after filtration were found to contain suspended matter upon standing for some time.

3. That solutions refiltered a number of times during thirty days showed no formation of insoluble material upon standing three days longer.

These facts, taken in connection with the results given in the preceding tables, would seem to establish the following principles:

1. That prolonged digestion is unnecessary in making determinations of soluble bitumen, in so far as the passage through the filter of finely divided insoluble organic matter is concerned.

2. That upon prolonged contact with bi.umens, carbon bisulphide causes the precipitation of small quantities of insoluble organic ma ter.

3. That this insoluble material is precipitated slowly, but that with the concentrations employed precipitation is practically complete within thirty days.

4. That for equal periods of time the greatest amount of precipitate is formed during the first twenty-four hours of digestion.

In view of these facts it seemed of interest to run a series of determinations of soluble bitumen with carbon bisulphide according to the cold method, allowing a minimum length of time for digestion and settlement. This was accordingly done, the filtrations being made 15 minutes after the sample was dissolved.

Table VII, which contains the results of these tests, shows this method to give excellent checks, and in Table VIII the four methods are directly compared.

TABLE VII.—FLASK METHOD, COLD; FIFTEEN MINUTES.

Material.	Solvent.	Soluble bitumen, per cent.	Insoluble organic matter, per cent.	Insoluble inorganic matter, per cent.	Ash in filtrate, per cent.*	Total.	Residue in flask, per cent.
Residual coal tar	Carbon bisulphide	78.07	21.88	0.05	....	100.00	0.03
		78.23	21.74	0.03	....	"	....
Residual water-gas tar	" "	99.23	0.70	0.07	....	"	0.03
		99.45	0.50	0.05	....	"	....
Residual petroleum	" "	99.80	0.09	0.11	....	"	0.01
		99.78	0.14	0.08	....	"	....
Blown petroleum residue	" "	99.75	0.15	0.10	....	"	0.00
		99.71	0.24	0.05	....	"	....
Bermudez asphaltic cement	" "	96.66	1.62	1.52	0.20	"	0.00
		96.58	1.53	1.69	0.20	"	....
Bermudez asphalt	" "	95.59	2.30	1.91	0.20	"	0.03
		95.40	2.45	1.95	0.20	"	....

*Averaged from Tables I, II, and III.

TABLE VIII.—PERCENTAGE OF INSOLUBLE ORGANIC MATTER; COMPARISON OF METHODS.

(Carbon Bisulphide.)

Method	Extractor.	Flask, Cold, 17 hrs.	Flask, Cold, 15 min.	Flask, Hot, 3 hrs.
Residual coal tar	18.90	22.89	21.88	21.15
	18.82	22.79	21.74	21.35
Residual water-gas tar	0.08	1.43	0.70	0.51
	−0.03	1.55	0.50	0.44
Residual petroleum	0.01	0.08	0.09	0.12
	−0.30	0.11	0.14	0.08
Blown petroleum residue	−0.10	0.16	0.15	0.19
	−0.24	0.16	0.24	0.17
Bermudez asphaltic cement	1.44	1.45	1.62	1.52
	1.56	1.52	1.53	1.46
Bermudez asphalt	2.29	2.25	2.30	2.25
	2.12	2.32	2.45	2.32

From these results the authors have come to the following conclusions with relation to the selection of a method:

1. That for the determination of soluble bitumen, carbon bisulphide is to be preferred to benzol for a solvent.

2. That the flask method with Gooch crucible is to be preferred to the extractor method.

3. That short periods of digestion are to be preferred to long ones.

4. Wi h regard to the final selection of a method, it is felt that either the cold 15-minute extraction or the hot extraction will give sufficiently close results for commercial purposes, and that there is little choice to be made between the two.

5. In favor of the latter, it may be urged hat for a determination of soluble matter this method is more scientifically correct, as it shows a somewhat smaller amount of insoluble organic matter.

6. On the other hand, it may be contended that the cold method gives a more correct idea of what it is desired to ascertain, namely, the percentage of insoluble material actually held in suspension; for it is believed that while the insoluble organic matter approaches free carbon in composition, a portion of it is composed of hydrocarbons rich in carbon, which are very slightly

soluble in the cold carbon bisulphide, but somewhat more readily soluble in the hot.

7. So far as this investigation has been carried, the 15-minute flask method would seem to be the most rapid practicable method yet found. It is not improbable, however, that the hot flask method could be shortened and that the quantity of solvent could be diminished somewhat in both.

Everything considered, the 15-minute cold flask method has been adopted by the laboratory of the United States Office of Public Roads until data are forthcoming to show that some other method is superior.

In conclusion, it may be said that these investigations will be continued by the authors, both with a view to determining the reaction which takes place between carbon bisulphide and bitumen, and the character of the products formed; and to compare further the various methods as applied to other bitumens and mixtures of various bitumens.

DISCUSSION.

Mr. Church.

MR. S. R. CHURCH.—Before undertaking a formal discussion of this paper, I just want to say a word expressive of the appreciation which I think all interested in the subject ought to feel toward Mr. Hubbard and Mr. Reeve and the laboratory which they represent for doing a work of this kind and presenting it before us in this way. It goes without saying that representatives of manufacturing concerns, however deeply they may be interested in the subject, are often unable, owing to stress of business, to devote the amount of time to such work that a government laboratory can; and for that reason I think we ought to be glad that these things have been brought out and also that they are open for discussion. I hope that any differences of opinion which we or other interests may have in regard to the methods which the authors have apparently found to be best, will be taken in good part and that they will lead to future work on their part and further elucidation of a matter which at present certainly offers large opportunities for differences of opinion.

Careful consideration of Messrs. Hubbard and Reeve's paper shows that whatever differences of any importance exist between the different methods that they have described, exist only in the treatment of tars. As applied to petroleum products, whether residual or blown, and also as applied to Bermudez asphalt and Bermudez asphalt cement, the figures given in the various tables are practically within the ordinary limits of error, regardless of the method followed or the solvent used.

This being the case, we may as well grant that so far as oils and asphaltums are concerned, the authors are possibly justified in their conclusion that carbon bisulphide is a rational solvent, and that a quick method without long digestion is as good as a method which involves 17 hours or 24 hours standing, as the case may be. Should their work along these lines be corroborated, as we have no doubt it will be, this shortening of the method will be welcomed by every one.

When it comes to testing tars, we are obliged to take issue

Mr. Church.

with the authors on a number of points. In the first place, they state that it is necessary or highly desirable to agree upon a method which is applicable to all bituminous materials, including tars, oils, artificial and native asphalts. One of the reasons given for this is that mixtures of any two or more may be counted as commercial products. Now so far as mixtures of tar and asphalt are concerned, while such mixtures are often used in road work, the proper way to test them, and the way they are being tested in cases that have come to my knowledge, is to test them separately before the mixture is made. This is the practice of the State Highway Departments of Massachusetts and New York, both of which use considerable quantities of tar-asphalt mixtures.

The determination of free carbon in tar and coal-tar pitch is a difficult one where accuracy is required. It may be asked whether in testing tars for road work, extreme accuracy is required, and this point is open to discussion. It is well, however, that the committee on this subject, and all members of the Society who are particularly interested in the matter, should know what has been the experience of those who have been testing tar and pitch for many years, and what conclusion they have reached as to the proper method for determining the actual amount of free carbon as nearly as accurate determination is possible.

At a meeting of the chemists of our company last winter, after considerable discussion and comparison of experiences with various modifications of the extractor method, the following method was adopted for use in all of our laboratories:

"Tar previously dried or dehydrated must always be used. In testing tars of 5 per cent. or more carbon content, 5 grams are taken; on lesser percentages 10 grams are used. The amount is weighed out into a 50-c.c. beaker and digested with toluol on the steam bath for a half to one hour. Two 15-cm. 575 S. & S. filter papers, the inner one to be cut to a diameter of 14 cm., are folded around a rod about $\frac{5}{8}$ in. in diameter, so as to form a long cylindrical filter cone. (These filter papers have been previously extracted with benzol to render them free from fat.) The cone is dried at 100° to 110° C. and placed in a weighing bottle and weighed after cooling. It is supported over a beaker by a wire or some convenient method. The toluol tar mixture is now decanted through this cone and the beaker washed with hot toluol until clean, all

Mr. Church. washings being passed through the cone. (A convenient 'policeman' to use in cleaning the beaker is a stout chicken feather trimmed so as to have a small fan at the end.) The filtrate should be carefully examined for any particles of free carbon and if there is any evidence of the same, it should be refiltered. Finally the cone is washed two or three times with hot C. P. benzol and is then transferred to the extraction apparatus, the filter cone being supported by a wire. C. P. benzol is used as a solvent, heat being applied by a steam bath, and the extraction is continued a number of hours until the descending benzol is completely colorless. The cone is then removed, dried as before, and weighed in the bottle after cooling. The balance used for the above determination should be accurate to 0.5 milligram."

The extractor method outlined by Messrs. Hubbard and Reeve differs from the method I have described in the following essential features:

First, in regard to solvents. The authors have chosen C. P. carbon bisulphide and commercial 90-per cent. benzol, giving as an excuse for using commercial benzol, the high cost of the C. P. product. If benzol were really a very costly reagent, we do not think that in any well-conducted laboratory this item of cost should cut much figure. Where a distinct difference in results is obtained, as is the case between commercial 90-per cent. benzol and chemically pure benzol, there is certainly no excuse for using the inferior reagent, even if the pure one is expensive. In this case, however, not even the item of expense should stand in the way. Merck and Company list C. P. benzol at 70 cents, and C. P. carbon bisulphide at 65 cents a pound, a difference of 5 cents a pound. C. P. benzol, however, can be had from the manufacturers in any quantity from one gallon up to a hundred, at prices from 50 cents to 30 cents per gallon, which is undoubtedly as cheap as carbon bisulphide in like quantities. It is very unfortunate that the authors' work, which should be of so much value, is clouded by the use of a solvent that should long ago have been discarded.

Our next point is a minor one, in regard to the quantity of bituminous material used for analysis. We think at least 5 to 10 grams should be taken, especially where the percentage of insoluble matter is likely to run as low as 5 per cent. or under.

We would strongly question the method used by the authors

in the extractor test in weighing tar directly onto the filter paper. In our opinion this accounts for the passing of insoluble matter through the filter, which was noted. If the tar is weighed into a small beaker and digested for a half-hour or an hour in hot solvent, this solvent decanted through the filters, and the insoluble residue then transferred to the filter, the passage of free carbon through the filter will be avoided. We prefer not to have the filter papers balanced because it is an advantage to cut the inner paper to a half-inch less diameter than the outer paper. Sometimes there occurs a creeping of the solvent over the edge of the paper, carrying insoluble matter with it, and having the outer paper of greater diameter than the inner prevents this. The authors make quite a point of the fact that by the extractor method, insoluble organic matter passes through both filters; but by observing these precautions, we have found that it does not pass through the filters, and we have used the same filter papers that the authors used—that is, No. 575 C. S. & S. **Mr. Church.**

The authors state from time to time in their comments on the various results of the different methods, that benzol was found to be the less powerful solvent, and that closer checks were obtained with the use of carbon bisulphide. They also state, in commenting on the poor check results with benzol, that such variations occurred only when different solvents were employed and not when two determinations were made from the same lot. This only shows the necessity for using pure benzol, and increases our surprise that it was not used.

Considering the figures given in the tables accompanying Messrs. Hubbard and Reeves' paper, I would call attention to Table I, fourth column, where the percentage of insoluble organic matter in residual coal tar, using 90-per cent. benzol, is found to be 38.76 on one test, and 30.46 on a check, whereas the actual percentage of insoluble organic matter in this sample, according to all the other tests made, ranged from 18 to 24, showing clearly that the extractor method, with benzol as a solvent, did not receive a fair test, since these results are entirely unreasonable.

In Table II, we find that the residual water-gas tar, using 90-per cent. benzol by the cold method, contained from 5 to 5½ per cent. of insoluble matter, whereas the percentage of insoluble matter as

Mr. Church. determined by other tests, using carbon bisulphide as the solvent, was from 0.3 to 1.55. Never in our experience have we found that water-gas tar contains any appreciable amounts of material insoluble in toluol and benzol, and soluble in carbon bisulphide.

There is only one other point that we wish to bring up, and that is in connection with the authors' conclusions, given as Nos. 4, 5 and 6 at the end of their paper. They say it may be considered that the cold method gives a more correct idea of what it is desired to obtain, that is, the percentage of insoluble matter actually held in suspension. They admit that a portion of this matter held in suspension and insoluble in cold carbon bisulphide, is soluble by hot extraction. Do the authors really contend that these hydro-

TABLE I.—FREE CARBON IN LOW, MEDIUM AND HIGH CARBON TARS, BY DIFFERENT SOLVENTS.

No.	Extractor. Hot. C_7H_8 and C_6H_6.	Extractor. Hot. C_6H_6 and $CHCl_3$.	Gooch. Cold. CS_2.
1. Low carbon	5.18 per cent.	5.02 per cent.	6.19 per cent.
	5.20 " "	5.28 " "	6.14 " "
2. Medium carbon	15.21 " "	15.43 " "	16.79 " "
	15.11 " "	15.85 " "	16.75 " "
3. High carbon	29.61 " "	29.27 " "	29.97 " "
	29.21 " "	29.41 " "	29.76 " "

carbons, difficultly soluble, are of no value as a binder in tar? While we are unable to agree at all with Mr. Hubbard's ideas as to the value of free carbon in tar from a standpoint of road treatment, as expressed in a paper read before the Society in 1909, we hardly supposed that he would include with the free carbon as an undesirable ingredient of tar, all portions of the material that can only be dissolved with difficulty.

Table I shows the results obtained recently at one of our laboratories with three samples of refined coal tar, known as Nos. 1, 2 and 3, containing low, medium, and high percentages of free carbon. Each sample was tested by the extractor method using (*a*) toluol for digestion and benzol in the extractor, and (*b*) benzol for digestion and chloroform in the extractor, as solvents; and also by the Gooch crucible method, using pure carbon bisulphide

as a solvent. The figures show clearly that the cold method with carbon bisulphide gave results from 1 to 1.5 per cent. high. The extractor method used was that which I have already described, and the Gooch crucible method was that described in the report of the Committee on Standard Tests for Road Materials, submitted to the Society last year.* **Mr. Church.**

In connection with this table, I will read from a letter received with the results of the analyses, which were made for me at our principal laboratory, where coal tar has been tested for many years and where, I suppose, more tar samples have been examined than at any other laboratory in the country:

"In all of these tests the filtrates and extracts were examined to be sure that no carbon had passed through, and any tests where this proved to be the case were rejected. There seems to be little difference between the effects of benzol and chloroform—this bears out our previous experience on that subject. The results with carbon bisulphide are consistently higher; this is undoubtedly due to the use of a *cold* solvent, our past experience having been that warm bisulphide gave slightly lower results than warm benzol under the same conditions.

"The Gooch method takes a very much longer time than the Knorr, as 15 hours' standing is specified, while a Knorr determination can be completed in a working day with ease; in fact, some of the tests by the latter method took less than 5 hours to complete. In the writer's opinion, also, the end point on a chloroform extraction is more difficult to determine than on a benzol extraction, owing to the drops being smaller in the former case, and hence these extractions have to be run longer than is really necessary in order to make sure that the extraction is complete.

"Between 150 and 200 c.c. of carbon bisulphide, besides the initial 100 c.c., were required to finish a test, a large part of which (at least one-third) was lost. On the benzol and chloroform extractions there was little loss of solvent. On the whole, by the benzol and Knorr method the least amount of the cheapest solvent was used, and the results seem very satisfactory from an operating point of view.

"Yours very truly,

(Signed) "J. M. WEISS."

Summing up: carbon bisulphide may be a good all-around solvent for bitumen when cold extraction is desired; but it should be borne in mind that cold extraction with carbon bisulphide or any other solvent does not give the actual percentage of free

* *Proceedings*, 1909, Vol. IX, p. 220.

Mr. Church. carbon in tars or pitches. When it is required to determine accurately the percentage of insoluble matter in these compounds:

1. A hot extraction is necessary.

2. Two solvents should be used. Toluol and benzol are rational solvents to use for this purpose, long experience having shown that they give consistent results. They are not dangerous or disagreeable, and, for hot extraction, carbon bisulphide is both dangerous and disagreeable.

Mr. Dow. MR. A. W. DOW.—The paper of Messrs. Hubbard and Reeve when taken as a whole is of value, first, because of its confirmation in a general way of the results of other analysts—that is, that cold carbon bisulphide is a better solvent than benzol; and second, because it places on record the fact that some bitumens are slowly precipitated from their solutions on standing. While this precipitation has been observed for several years past and commented upon by myself and others on several occasions, I believe I am right in saying that it has never before been publicly recorded. The cause of the precipitation has never been thoroughly investigated, but it has been ascertained that it is not caused in all cases by the action of light on the solution or by the concentration of the solution; in fact, on the contrary, in many cases it takes place to a less degree in concentrated solutions than in dilute solutions. Judging from this, I believe that in many cases the heavy oils contained in some bitumens are better solvents for the harder portions of the bitumen than the solvents used for the extraction. This is substantiated by two facts: I have found that a more complete extraction can be effected by starting with but little solvent, thus keeping the solution concentrated; and then it is a well-known fact that concentrated solutions of some bitumens filter more readily than do dilute solutions.

From a critical analysis it is readily seen that this paper, instead of placing the subject of the solution of bitumens upon a more rational basis, has rather added to the already existing confusion; and even if the results had been more in accord with those of other analysts, it would yet be impossible, judging from the work as published, to consider any method given by the authors as one that could be universally adopted for the determination of soluble bitumen. This is because they have not selected typical bitumens for their work; their results and pos-

sibly their conclusions would be considerably different if materials such as Trinidad, Maracaibo, Cuban and other asphalts and bituminous paving mixtures had been used in the investigation. **Mr. Dow.**

Cold benzol has never been suggested as a solvent for bitumens and it is well known that it does not give concordant results. Hot benzol has not been used on asphalts, but it is a better solvent for some coal tars than carbon bisulphide. Hot benzol appears to dissolve some bitumens that carbon bisulphide does not, for, after extracting with cold carbon bisulphide, still more bitumen can be extracted by treating the residue with hot benzol. I have never used the combination method of hot benzol and hot toluol for the extraction of bitumen from coal tars, but I have found that a cold carbon-bisulphide extraction followed by the hot benzol extraction gives results very close to those obtained by other analysts with the benzol-toluol method. For accurate results, I believe that long digestion, which allows of subsidation, is to be preferred for the majority of asphalts and paving mixtures, but that short digestion is much more preferable for coal tars.

MR. W. H. FULWEILER.—It is natural that I should agree with Mr. Church in at least a general way because our laboratories have been working rather closely together along this line. We too have found that the double solvent method of extraction seems to be preferable for coal tars. In the case of water-gas tars there is, I think, some slight difference. We have found that when we extracted with hot benzol or toluol, the combustion of the residue gave results ranging in carbon from 93 to 94 per cent., whereas by using carbon bisulphide, we raised the purity of the residue to from 96 to 97 per cent., showing that there are some materials which can undoubtedly be extracted with hot carbon bisulphide. **Mr. Fulweiler.**

Commenting generally on the authors' paper, I would say that we never use 90-per cent. benzol; we always use the chemically pure solvent, and that rather precludes direct comparison. As to the difference between hot benzol extraction and the cold carbon bisulphide extraction, I found the latter a slightly better solvent than hot benzol. In that we take issue with Mr. Dow, who has found the reverse. I regret that the authors did not try some of the double solvents on the tars, because, as Mr. Church brought out very clearly, while the single solvents seem to check well with materials containing low percentages, yet for tars containing high

Mr. Fulweiler. percentages we shall have to turn to a method employing double solvents in order to secure closely concordant results. Personally I feel that it might be well to confine ourselves to hot carbon bisulphide. I recognize that it is a distinctly disagreeable material to use, although we have had no trouble on that account because we use a large hood. But in large laboratories the loss of material is an item to be considered and there is the ever-present danger of fire. However, on account of its general availability for practically the whole range of materials used in road work, it seems to be the most generally useful solvent.

Mr. Sommer. MR. ALBERT SOMMER.—I do not wish to add very much to what has been said here by gentlemen who have had much experience along this line; but I may say that it appears to me that the summary of Messrs. Hubbard and Reeve's paper indicates that the hot extraction method is preferable to, and much more reliable than, the cold one. I have always advocated the use of this method. Their own figures seem to indicate that the results by the hot process are much more concordant and uniform. Besides, if I correctly understand the authors, they state that by the cold method, thorough extraction and thorough precipitation of insoluble matter can be achieved only after standing a very long time. Therefore, from the standpoint of quick working, and also from the standpoint of desiring an automatic process which is absolutely independent of the personal equation, I cannot but find further reasons for the hot method given in this paper.

The authors' statement as to the price of benzol should not, in my opinion, be taken into consideration. In our commercial laboratories we do not care how much a chemical costs. What we consider is the price of labor, speed and accuracy. However, I have found only within the past few days that benzol is now being manufactured absolutely chemically pure, and can be obtained at the price of 42 cents a gallon, which is practically the same as the price of carbon bisulphide. Under these circumstances it seems to me unwarranted to apply 90-per cent. benzol, the remaining 10 per cent. of which might be anything but benzol. I have found that chemically pure benzol has an almost constant boiling point and gives no Thiophen reaction. I should say we ought to be content to use benzol in preference to carbon bisulphide.

Furthermore, it is not quite clear to me how the authors determine the percentage of insoluble matter by the hot extraction method. We do not weigh the filter paper, but we dry the cartridge with its contents at 105° C. after extraction, and we then brush the insoluble matter into a weighed watchglass and weigh it. This method is much more accurate than that by which the insoluble matter is weighed *with* the filter paper, which might undergo changes during the extraction. **Mr. Sommer.**

MR. P. HUBBARD AND MR. C. S. REEVE (*by letter*).—Upon reviewing the discussion of our paper by Messrs. Church, Dow, Fulweiler, and Sommer, a considerable variance will be noted in the views of these gentlemen. For this reason the authors have thought it best to present a brief reply in defence of the conclusions presented in the paper. **Messrs. Hubbard and Reeve.**

Realizing that some cause for criticism lay in our use of 90-per cent. benzol, and finding that the chemically pure product could be obtained at a much lower price than previous quotations, furnished us by dealers in chemical supplies, had led us to believe, we employed this material as a solvent both according to the 15-minute cold extraction method and the hot extractor method described by Mr. Church. The residual coal tar and the residual water-gas tar were selected for these extractions. C. P. toluol was also used as a solvent according to the 15-minute cold method. The results obtained are tabulated below, together with those given by the 15-minute cold extraction with carbon bisulphide.

PERCENTAGE OF INSOLUBLE ORGANIC MATTER.

Material.	Extractor C_7H_8 and C_6H_6	Flask Method—Cold—15 Minutes.		
		C_6H_6	C_7H_8	CS_2
Residual coal tar	22.36	25.00	24.75	21.88
" " "	21.01	24.46	24.55	21.74
Residual water-gas tar	.....	5.22	5.37	0.70
" " " "	.....	4.64	4.64	0.50

It will be seen that these results serve only to confirm our original conclusions as to the best general solvent. It may be added that we found the method described by Mr. Church to be both tedious and awkward. And while Mr. Church confidently asserts that no insoluble organic matter passes through

Messrs. Hubbard and Reeve.

the filters, the first sentence of the letter in connection with his results states that "any tests where this proved to be the case were rejected." It would be of value to know how many tests it was necessary to reject in order to get these results, as this is one of the very weak points of the extractor method.

Mr. Church's table also shows that tars have a higher solubility by his method of analysis than by long digestion in carbon bisulphide as proposed by the Sub-Committee on Bituminous Road Surfacing Materials at the annual meeting of the Society in 1909.* We feel confident, however, that had he tried a 15-minute digestion with carbon bisulphide, he would have obtained results for insoluble organic matter as low as those by his own method, and, more likely, lower, as we have clearly shown that there is a continual formation of material insoluble in carbon bisulphide as the length of the digestion increases.

In Mr. Church's criticism of our belief that it is most necessary to select a solvent and method of extraction suitable for the determination of soluble bitumen in all or the greatest number of bituminous materials, owing to the fact that mixtures of any two or more may be encountered as commercial products, he makes the following statement: "Now so far as mixtures of tar and asphalt are concerned, while such mixtures are often used in road work, the proper way to test them, and the way they are being tested in cases that have come to my knowledge, is to test them separately before the mixture is made." In regard to this point, we would call Mr. Church's attention to the fact that there are at present upon the market a number of trade products composed of a mixture of tar and oil or asphalt. The manufacturers of these products do not, of course, wish to make public either their process of manufacture or the proportions of the various constituents of their products. In such cases, therefore, it is manifestly impossible to employ methods particularly adapted to the determination of soluble bitumen in each of the constituents. Moreover, if the method suggested by Mr. Church was universally followed, it would be necessary for each consumer to make such mixtures himself or have inspectors present while the manufacturers were making the mixtures. Another objection to such a procedure, even if generally practicable, would be that the

*Appendix Report of Committee H, *Proceedings*, 1909, Vol. IX, p. 220.—ED.

Messrs. Hubbard and Reeve.

determination of soluble bitumen in the individual constituents of a mixture does not necessarily give a correct idea of the percentage of soluble bitumen in the mixture, as the process of mixing may or may not be attended by cracking and the formation of insoluble material.

In reply to Mr. Church's question as to whether or not the authors believe that hydrocarbons in tar difficultly soluble in carbon bisulphide are of value as a binder, we would refer him to the paper by one of us, which has been mentioned. In this paper it will be found that the binding capacity of a tar containing a given percentage of insoluble and difficultly soluble material, is lower than that of a tar of similar consistency obtained by removing a portion of the insoluble and difficultly soluble material.

The authors regret that official duties have interfered with their making more extended investigations in preparation for this discussion, and more especially along the lines suggested by Mr. Dow. While Trinidad asphalt, as previously noted, was purposely omitted from consideration, it would undoubtedly have added to the value of our conclusions if we could have included results obtained from the extraction of other asphalts. Nevertheless, we still think we have selected for our work six bitumens which are typical of practically all the materials going into road binders at the present time. Trinidad asphalt is an exception, and where its presence is indicated, a method of longer subsidence will very likely be necessary.

IMPROVED INSTRUMENTS FOR THE PHYSICAL TESTING OF BITUMINOUS MATERIALS.*

By Herbert Abraham.

An Instrument for Ascertaining the Tenacity and Ductility of Bituminous Materials.

The term "ductility" as applied to bituminous substances refers to the extent that they are capable of being drawn out in the form of a fine thread. In the case of soft bituminous substances, this property may be roughly determined by stringing out a small quantity between the thumb and forefinger. Materials possessing great ductility are very often described as "stringy" or as showing "life," whereas those of low ductility are said to be "short" or "dead."

Several instruments have been devised for determining the ductility of bituminous materials. Although differing slightly in construction, they operate on substantially the same principles, measuring the extension which the bituminous substance is capable of sustaining without fracture.

The ductility test first assumed importance in connection with asphaltic cements used for paving purposes. It was probably for this reason that the form of mold which originally suggested itself for retaining the asphalt during the test† was patterned along the lines of the briquette mold ordinarily employed in connection with hydraulic cements. This same type of mold has been adhered to in a ductility machine since described by Smith.‡

During recent years, the scope of the ductility test has been extended to bituminous materials other than paving cement, including various asphalts, tars, and pitches employed in manufacturing insulating materials, rubber substitutes, paints, varnishes, waterproof fabrics, etc. It has, for example, been found that

* This is the second paper on this subject by the author. See paper of same title, *Proceedings*, 1909, Vol. IX, pp. 568–579.

† Described by Dow in *The Chemical Engineer*, 1905, Vol. I, No. 5, p 330, *et seq.*

‡ "A Machine for Testing the Ductility of Bituminous Paving Cements." *Proceedings*, 1909, Vol. IX, pp. 594–599.

bituminous substances having the same degree of hardness (consistency) and melting point (fusibility), but varying in ductility, will behave differently towards heat and cold, and in solution. Thus, substances possessing great ductility are readily susceptible to changes in temperature, will melt easily to thin liquids, and when dissolved will form solutions of low viscosity. On the other hand, substances endowed with but little ductility will be least affected by changes in temperature, will melt to "pasty" liquids, and will form solutions of high viscosity.

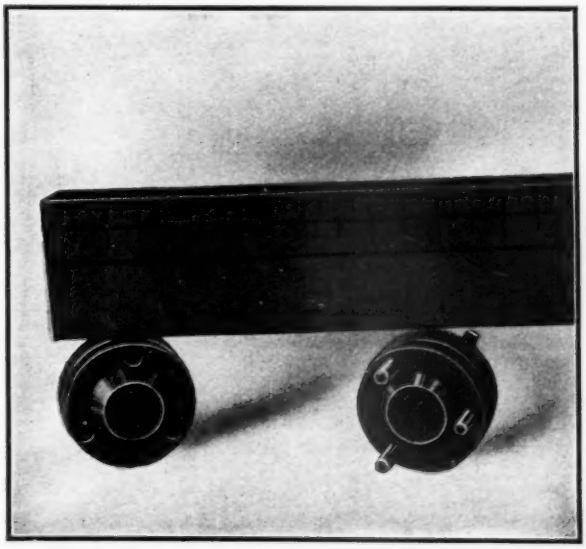


FIG. 1.

Although the Dow type of mold is well fitted for handling paving cements, it is hardly adapted to receiving and retaining many of the bituminous materials ordinarily encountered. Soft semi-liquid substances are apt to run out of the mold, and hard brittle asphalts, owing to its form, are liable to be fractured while it is being attached to the clamps.

Recognizing the fact that the mold constitutes the most vital part of the entire instrument, it was subjected to careful study, and after extended tests, the form illustrated in Figs. 1 and 2 was

adopted as giving the best results and overcoming the difficulties mentioned.

The mold consists of two cylindrical bronze sections, a_1 and a_2 (Fig. 2), resting together on circular knife-edges and maintained in that position by three guide rods b. The cross-section at the knife-edges is exactly one square centimeter. The further ends of these two cup-like sections are threaded, and bear the caps c_1 and

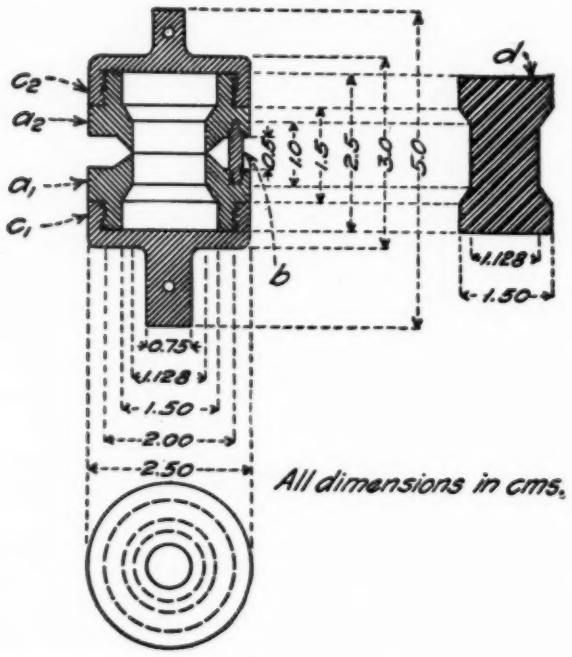


FIG. 2.

c_2, which serve to fasten the mold in the instrument. The interior of the mold is amalgamated with mercury to prevent the bituminous material from adhering. This may be effected by using a solution of mercuric nitrate or mercuric sulphate.

After warming the mold it is filled by unscrewing the upper cap c_1 (Fig. 2), bringing the two sections firmly together and pouring in the melted bituminous substance, which assumes the form of a rivet as illustrated by d, the smallest cross-section of which has an area of *exactly* one square centimeter.

A photograph of the "tensometer" is shown in Fig. 3. The bronze mold A_1 and A_2 is clamped between the two guides B_1 and B_2, the lower section being fastened to the stationary cross-piece C by means of the pin D_1 and the upper section to the movable cross-head E by the pin D_2. The cross-head is attached to a chain F, which passes over the chain-wheel G fastened to the spring balance H, and then around a suitable winding mechanism I. The winding is effected by turning the handle J, which operates the endless chain K running on the sprocket wheels L_1 and L_2.

The spring balance is equipped with a trigger M to prevent recoil when the spring has been extended. The trigger may be conveniently released at the end of the operation.

The chain F also meshes with a train of gears operating the brass pointer N pressing against the dial O, which is formed of vulcanite or other insulating material. Its face is divided into one hundred divisions, each consisting of a metallic contact. As the pointer brushes over these metallic contacts, it momentarily closes an electric circuit which operates the relay P, causing an audible "click." The relay is connected with the batteries Q and the switch R. One revolution of the pointer indicates that the halves of the mold have been separated a distance of exactly one meter. Therefore, a movement of the pointer over one division of the dial corresponds to a centimeter rise of the section A_2. The gearing is shown in detail in Fig. 4.

The guides B_1 and B_2 (Fig. 3) are pivoted at S_1 and S_2, which permits the reservoir T being slipped into place. After this has been done, the guides are prevented from moving by the bolt U which firmly locks them in position. The reservoir is filled with water maintained at any desired temperature by the heating coil Y in series with the incandescent lamps V. The bath may be conveniently agitated by squeezing the bulb W which forces air through the liquid. The valve X is for emptying the reservoir.

The tensometer measures 77 ins. in height, 15 ins. in width at the top and 22 ins. at the base. The reservoir stands $45\frac{1}{2}$ ins. high, so as to permit the sections of the mold being separated 39.4 ins. or 100 cms.

After the mold containing the bituminous material is fastened into place, it is brought to a temperature of exactly 77° F., registered by a thermometer suspended in the liquid. The maximum-

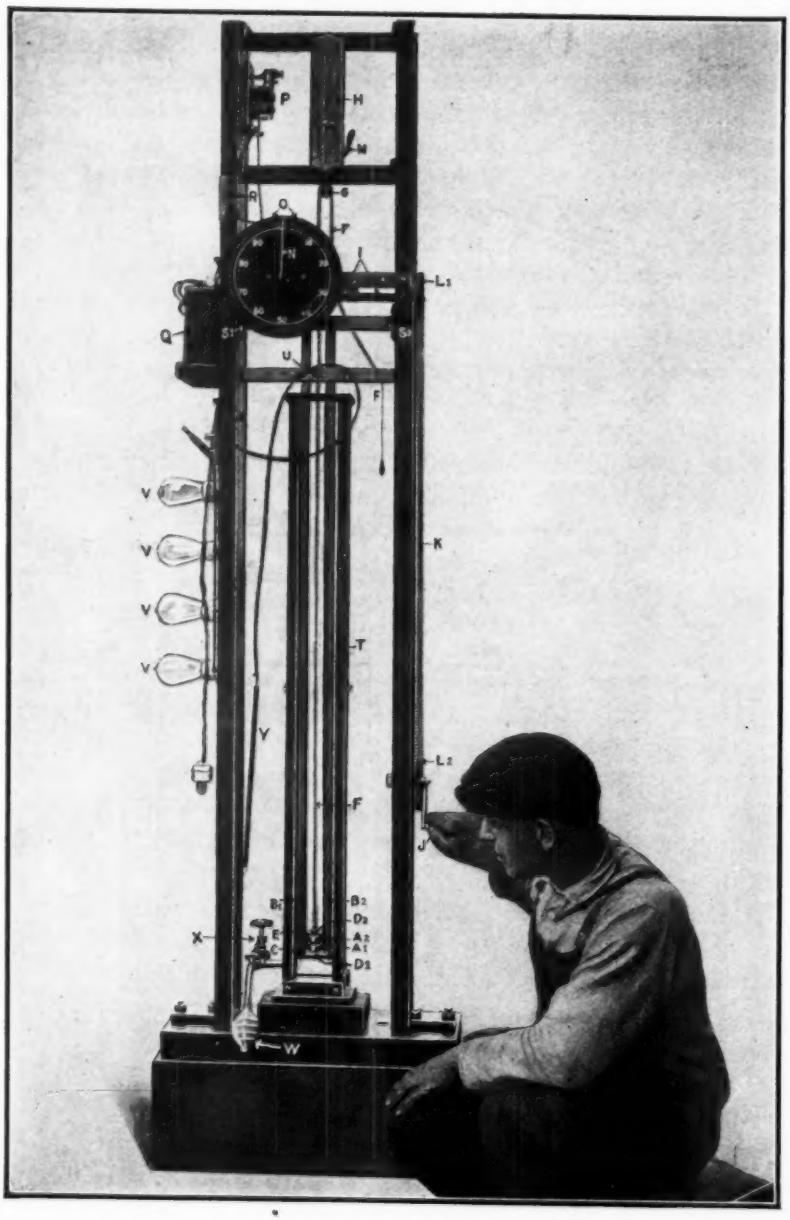


FIG. 3.

indicator of the spring balance is then set at the zero mark, and the pointer on the dial also brought to the zero division by winding up the chain until it becomes taut. The electric circuit is then closed by means of the switch R, and the crank turned so as to draw apart the two sections of the mold at the definite speed of *five centimeters per minute*. The speed may be conveniently controlled by a metronome equipped with a bell adjusted to ring every twelve seconds or five times per minute. The

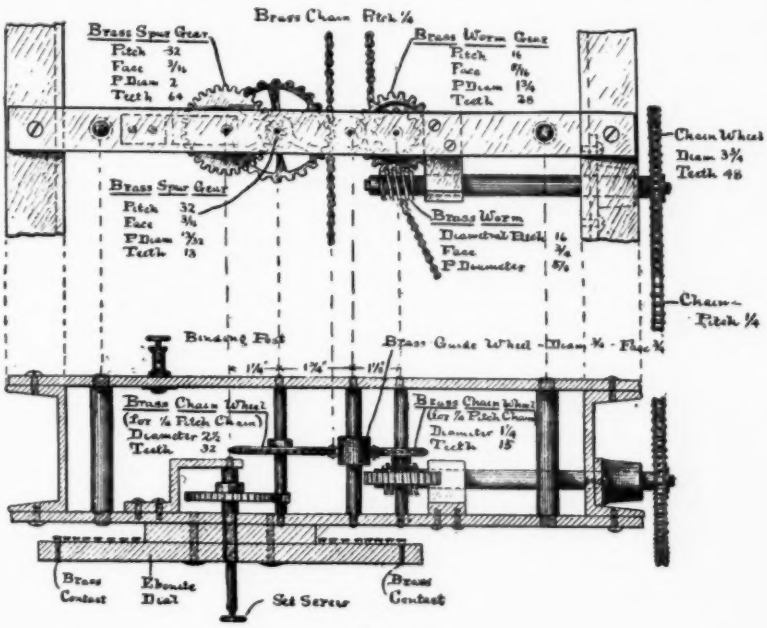


FIG. 4.

speed at which the crank is turned must then be regulated so that the "clicks" of the relay are brought in unison with the "rings" of the metronome.

The operator should watch the specimen as the sections A_1 and A_2 separate, and he should cease turning the crank at the moment the thread of bituminous material parts. The spring balance will indicate the tenacity of the substance expressed in kilograms, and the dial its ductility expressed in centimeters. On account of the particular construction of the instrument, the

actual stress applied to the specimen is one-half of the reading of the spring balance.

The tensometer may be conveniently used to test bituminous materials of any consistency. Its range is sufficiently great to handle all forms of asphalts, tars, and pitches in commercial use. A spring balance reading to 20 kilograms divided into tenths of a kilogram, which corresponds to a maximum tenacity of 10 kilograms per sq. cm., is sufficient for all practical purposes. As yet, no bituminous material has been encountered having a ductility greater than 100 cms. The highest tested by the writer showed a ductility of 82 cms.

The tensometer possesses the following distinctive features:

1. It is designed to determine both the tenacity and ductility of bituminous materials in a single operation.

2. It is capable of handling hard and brittle, as well as soft and semi-liquid substances.

3. The mold is constructed according to scientific principles, and it may readily be filled or cleaned.

4. Only a very small quantity of the bituminous material (between 3 and 4 grams) is required for the test.

5. The manner of conducting the test is extremely simple. It is but necessary to turn the crank so that the "clicks" of the machine are maintained in unison with the "rings" of a metronome, and to observe when the thread of bitumen parts. The tenacity and ductility are recorded automatically.

The instruments described in this and in the preceding paper may be used to determine the following physical properties of bituminous materials:

Consistency.—The substance is subjected to a compressive stress applied locally to its surface, so as to cause a round flat surface 0.01 sq. cm. in area to penetrate to a depth of exactly one centimeter in one minute. The square root of the maximum reading in grams is equal to the "consistency."

Resilience.—At the termination of the preceding test, the load is immediately released, and at the end of one minute the rebound is noted and expressed in percentage of a centimeter. This is equal to the "resilience."

Fusibility.—A glass tube of 6 to 7 mms. internal diameter containing a plug of the substance 5 mms. in length and 5 grams of

mercury, is heated at the uniform rate of 4° F. per minute. The temperature at which the mercury drops through the plug of material is equal to its "fusibility."

Tenacity.—The material is subjected to a tensile stress applied to a cylinder of exactly 1 sq. cm. cross-section and 1 cm. in length, so as to cause it to be drawn apart at the uniform speed of five centimeters per minute. The maximum reading in kilograms is equal to the "tenacity."

Ductility.—The elongation in centimeters at the moment the material parts in the preceding test, is a measure of its "ductility."

DISCUSSION

Mr. Skinner. MR. C. F. SKINNER.—I should like to ask the author whether any arrangement is made to take care of the changes in the temperature of the sample being tested during the drawing out.

Mr. Abraham. MR. HERBERT ABRAHAM.—I would say that the reservoir shown in the illustration, designated T, is filled with water, and the heating coil, Y, is connected with the incandescent lamps, P, which are used to maintain the temperature at exactly 77° F., or in fact at any temperature that may be desired.

Mr. Dow. MR. A. W. DOW.—I desire to compliment the author on the presentation to this Society of papers descriptive of two very interesting instruments. As they are more scientifically constructed than anything that has been used heretofore for this purpose, they will no doubt prove very valuable in studying the physical properties of bitumens.

From my experience with the ductility test on bitumens, I agree with Mr. Abraham in the statement that the mold constitutes the most vital part of the instrument in making this test; but I believe the author is wrong in adopting the mold shaped as described in his paper. In my first paper on "The Testing of Bitumen for Paving Purposes," read before this Society in 1903,* I mentioned the ductility test and there advised the use of a test piece or briquette of bitumen 5 cms. long, with a uniform section of one sq. cm. throughout its entire length. I found, however, by the use of a test piece shaped like this that the distance pulled out was much more dependent on the homogeneity of the material under test than upon the ductility such as we interpret the meaning of this word in speaking of asphalt. The cause of this is readily appreciated when the conditions of the test are looked into. If the material to be tested is homogeneous, this prism on being pulled out will contract equally at all points. If, however, the material under test is not homogeneous, there must of course be some points in the prism weaker than others and the stretching will naturally take place at these points to varying degrees, depending on their relative weakness. To overcome this difficulty, the

Proceedings, 1903, Vol. III, p. 349.

form of briquette which we now use was devised; that is, a briquette which tapers from 2 cms. in width to a minimum cross section of 1 sq. cm. at the center. **Mr. Dow.**

I think Mr. Abraham will obtain the same results with his shape of mold as I did with my former one. Have you not found such to be the case, Mr. Abraham?

MR. ABRAHAM.—Not exactly. I have noticed that specimens of pitch behave very much like specimens of steel tested in a similar manner. I might illustrate this by a diagram (drawing on the blackboard an outline similar to that shown in Fig. 2).* The shape at the beginning of the test is like that, but at the termination, the substance will look something like this (drawing another diagram in which the side indentations are more flattened out, the cross section being narrower and higher). In other words, the bituminous material will not adhere to the containing cylinder, but will stretch lengthwise, producing a minimum cross section. If the material is very impure, it will of course be necessary to remove the larger lumps of mineral matter by screening through fine wire sieves. Any fine particles distributed homogeneously throughout the mass need not be removed, for they will not interfere with the test. **Mr. Abraham.**

Duplicate tests check up very nicely and this is all that can be desired. The instrument is designed to test bituminous materials as they occur commercially, and it is not necessary to remove all the mineral matter unless this is especially desired.

MR. J. W. HOWARD.—Mr. Abraham has contributed something of value to the asphalt industry. Many thousand ductility tests in my laboratory show that it is necessary to have a reduced central section of the test piece. If the section of Mr. Abraham's test piece were contracted at its center, it would be more free from danger of slight adhesion to the mold. **Mr. Howard.**

The word "consistency" is used by few of us; "penetration" is the general term. For the sake of uniformity, I would suggest keeping the latter term. "Fusibility," in the minds of most men, refers to substances needing a great deal of heat for melting and the term usually applied to bitumens is "melting point." Each apparatus gives a different result. I have a mercury apparatus, and therefore

* See p. 446.—ED.

Mr. Howard. I always record the melting point as that obtained by the "Howard mercury method," "test-tube method," etc. "Tenacity" may refer to the internal cohesion of the mass, or it may mean adhesion to exterior substances or to impurities within the bitumen. There are in progress in my laboratory and elsewhere several thousand tests of adhesion. I hope to bring out next year some results from using a standard sand and many bituminous substances.

Mr. Abraham. MR. ABRAHAM.—I purposely refrained from using the term "penetration" and substituted the term "consistency." This was done advisedly. I realize that a number of results in present practice are reported as "penetration," referring of course to the Dow instrument. The instrument which I described in my paper gives entirely different readings, and if both of these results were termed "penetration," confusion would certainly result. Inasmuch as they are entirely different, I thought it wise to substitute the term "consistency" to describe the readings of my instrument.

Many pure organic substances melt at a definite temperature, passing immediately from the solid to the liquid state, and to these the term "melting point" has been appropriately applied. In the case of bituminous substances, however, there is no marked transition between the solid and liquid states, for these pass through several intermediate plastic states. The test which I described is an arbitrary one and therefore the results should not be described as the "melting point." For this reason I thought it desirable to substitute the term "fusibility."

The term "tenacity," which I have used, is in my mind comparable to the same term as ordinarily applied to specimens of steel or other metals, and refers to the "tensile strength" of the material tested.

Mr. Howard. MR. HOWARD.—It is true that the use of a blunt-pointed instrument in determining penetration or consistency is superior to the pointed needle. The results are more definite and uniform. The pointed needle progresses at a more rapid rate when it starts than the rest of the needle, and the results are arbitrary. I hope the day will come when every one will use blunt-pointed needles, and not the needle point. It is hard, however, to make a change which would affect the records of so many hundred cities, records on which we depend to reproduce work. A factor table has been

prepared by Mr. Abraham for conversion of pointed needle readings to blunt-end needle readings. Mr. Howard.

MR. HENRY W. FISHER.—I have been very much interested in Mr. Abraham's description of his apparatus, which is most ingenious. In connection with this subject, I wish to make mention of a special simple device which I designed for determining viscosities, and by means of which some of the physical properties of insulating compounds can be analyzed. The apparatus consists of an iron casting, cylindrical in shape and open at the top, with a bracket at the top by which it can be fastened to the wall so that the center of the cylinder is vertical. The inside dimensions are, diameter $3\frac{3}{8}$ ins., length $5\frac{1}{2}$ ins. In the center of the bottom, which is $\frac{1}{2}$ in. thick, is a $\frac{1}{4}$-in. circular hole at the outside of which is a cut-off knife valve. The cover is of iron and is screwed on over a rubber gasket. Over the bottom part of the casting is wound a coil of No. 3 B. & S. G. asbestos and cotton-covered wire, the coil being about 4 ins. long and having an outside diameter of 6 ins. Into the sides in the 2-in. space above the coil are fitted three connections. One goes to an automobile tire pump; one to a 300-lbs. per sq. in. pressure gage and one to a manometer by which small pressures are read. Imbedded in the iron near the $\frac{1}{4}$-in. hole at the bottom of the iron is a thermal couple by means of which temperatures are accurately read. Mr. Fisher.

In using the apparatus, the compound to be tested is first melted and poured in, to a depth of 3 ins. Then the top is screwed down firmly, and an alternating current is applied to the coil which heats the iron inductively. With proper regulating apparatus, any desired temperature can be maintained. I use a maximum of 50 volts, which can be reduced by steps of one per cent. After equilibrium of temperature is reached, pressure is applied by the automobile pump, the valve at the bottom is opened, and the amount of compound flowing through the hole in a given time, as determined by a stop-watch, is measured. In like manner other tests are made at other pressures and at the same temperature, and a curve is plotted by means of which is found the pressure necessary to force out a standard amount per minute. This pressure multiplied by a constant represents the viscosity. Similarly, other tests can be made at different temperatures and the change of viscosity with change of temperature

Mr. Fisher. determined. If a different rate of flow is used, the relative viscosities of different compounds will also differ; hence the need of using a standard rate of flow.

Now it may be asked: What is the value of these tests? To elucidate, I will state that for saturating purposes compounds of good flowing properties are required, while for other uses compounds more of a rubbery nature which will not flow under considerable rise in temperature are necessary. The amount of material forced out in the case of some compounds at ordinary temperatures is found to vary directly as the applied pressure, while with others the amount varies as the fourth power of the pressure. In the first case, by halving the pressure one half of the material would flow out. In the second case, by halving the pressure only one sixteenth of the material would flow out. Hence, compounds of the first class are good for saturating purposes while those of the second class are not.

This apparatus cannot be used in testing compounds at temperatures where they are very brittle. It can be used to measure compounds at temperatures slightly above the melting point, so that when used in connection with a Doolittle viscosimeter, viscosities can be determined through a wide range of temperatures and many other interesting properties of compounds investigated.

I should like to know if any one present has used this method of testing compounds.

Mr. Pullar. MR. H. B. PULLAR.—It is recognized by everybody in the asphalt business that a material having a large ductility at 77° F. does not necessarily retain a large ductility at other temperatures, either higher or lower. I should like to ask Mr. Abraham if the springs in his apparatus for measuring the tensile strength are strong enough to be effective at different temperatures, ranging from 32° F. to 100° F., and whether concordant results can be obtained. It seems to me that the most practical and useful results can be obtained only by taking the ductility tests at a range of temperatures, and if Mr. Abraham's apparatus can do this successfully it will prove to be of great value.

The usefulness of the ductility test at 77° F. has not yet been satisfactorily proven and in my opinion is of very little value. A machine which would indicate the ductility and tenacity only at this one temperature I would consider of little value.

MR. ABRAHAM.—In answer I might say that the instrument may be operated at all the conventional temperatures. I merely mentioned 77° F. as a specific illustration. There is no reason why the reservoir should not be packed with ice, or a mixture of ice and salt, for testing at low temperatures. The heating coil will take care of high temperatures, and may be used to maintain the bath of liquid at any degree of heat from the room temperature up to the boiling point of water. If paraffin oil is used as the heating medium the temperature may be raised above 212° F. **Mr. Abraham.**

The spring scale is adapted to all temperatures, and certainly as low as 32° F., unless the material is very hard. Thus, for example, a hard asphalt of the nature of gilsonite will not show any appreciable ductility at a temperature of 32° F., and I doubt whether spring scales reading to but 20 kilograms would answer. In this case we could easily substitute for the spring another reading to a greater number of kilograms, and so on, without limitation.

NECESSARY REFORMS IN SPECIFICATIONS FOR PETROLEUM PRODUCTS.

By Albert Sommer.

It is scarcely too much to maintain that there are few industries to-day which are not dependent, in one way or another, on products made from crude petroleum. No wheel can turn without lubrication, and the time has long since passed when oil lubricants were taken exclusively from the vegetable or animal kingdom. The list of products which are being made from crude mineral oil is growing every day, and what were called "by-products" by old-time petroleum refiners have now relegated to comparative insignificance what was formerly the main product, namely, burning oil. Hundreds of various products originate from crude petroleum, the tonnage of some of which is as great or even greater than that of kerosene or burning oil. The main groups are as follows:

1. Gasoline, benzine, and naphtha.
2. Burning fractions.
3. Intermediary fractions (used for gas and fuel purposes).
4. Lubricating fractions.
5. Residuals; in the case of asphaltic oils: asphalt.

In greatest contrast to the consumption and importance of these mineral products, we have to state the fact that the methods of testing on which most purchasers of these products depend, be the consumers individuals, corporations, or governments, are the same as were devised during the infancy of the petroleum industry. They originated principally from the desire of having "tests" at any rate, regardless of their actual bearing on value, so that the consumer could have the quieting sense of having bought by some kind of a standard. Tests which were available were those for specific gravity, flashing and burning point, cold test, and perhaps color test; and for a great many oil concerns they still represent the entire répertoire of the chemical laboratory. These tests could never be considered as determining the value

of an oil in actual use, and will, at best, be only descriptive; they are entirely inadequate for modern conditions, and no specification for petroleum products should be based exclusively on tests of that character.

The entire field of these products cannot be covered in the following discourse, but it will be shown by a few examples, chosen from fields of the most general interest, that some reforms are an urgent necessity.

Gasoline.—One of the most striking examples is gasoline, the use of which has assumed vast proportions since the introduction of the explosion engine. It represents the lightest fraction of crude petroleum and is still largely sold by its specific gravity, which in nine out of ten specifications is the principal quality demanded. We read that gasoline should have a specific gravity of not less than 67° or 70° Baumé. Specific gravity itself being no measure for actual service, we have to demand, why is such importance being attributed to it? It has developed into a habit of oil refiners to judge fractions obtained from one and the same crude product by specific gravity; the still man judges the progress of his operation by the change in specific gravity of the distillates which gradually come off the condenser. For this reason it has become habitual to also designate those fractions to the outside world by their specific gravity, and for the consumer to base his purchases on it—a course which is no longer justified.

The world is drawing its supplies to-day from a great many various oil fields. The crude oils are neither physically nor chemically identical with one another. An oil which contains less hydrogen to the molecule than another will be the heavier oil. Fractions obtained from two different crude oils (for instance, from Pennsylvania and Texas) might boil between the same temperatures, and yet differ considerably in specific gravity, as much as 20° Baumé. Both products, if they are naphtha or gasoline, might of course be equally valuable to the consumer.

For all uses of gasoline, without exception, its value is based chiefly on its volatility, because in all gas engines the ultimate combustion is a gas reaction. This characteristic of a power naphtha will always determine its value to any consumer; and if we start with the theory that a commercial test should represent or describe the value of a certain product in actual use, we should

allow for specifications only such methods of testing which elucidate such value. To test volatility the best available method is the distillation of 100 cc. by the Engler method; the distillation should be carried out quickly (10 cc. per minute) and the temperature taken whenever 10 per cent. is distilled. The apparatus is specified in detail by the International Petroleum Congress.

Without going into detail as to which figures should be demanded, it might be mentioned that for very high-speed, light motors, a product must necessarily be more gaseous and have a lower boiling point than would be required for heavy-duty gasoline engines, which can burn a heavier fuel to greater advantage. As a general rule, it may be stated that the ideal fuel for a gas or gasoline engine would be one which would have the most homogeneous character or be as "short" a fraction as possible, for the reason that with such a fraction a theoretical mixture with air can be made and consequently much higher efficiency obtained. It cannot be too strongly demanded that in all specifications for light petroleum products the distillation test alone should be considered important. As examples, specifications for two motor fuels are submitted as follows:

SPECIFICATION FOR GASOLINE A (For high-speed motors).

1. To be high-grade, refined, and de-odorized gasoline, free from all impurities.
2. When distilled in an Engler apparatus, applying 100 cc. at the rate of 10 cc. per minute, thermometer in vapor, it must show the following:
   (*a*) The boiling point must not be above 130° F.
   (*b*) One hundred per cent. must distill over below 280° F. Not less than 97 per cent. should be re-condensed and the distillation should be driven to the "end point," which is indicated by the appearance of white vapors in the flask, and immediately discontinued.

SPECIFICATION FOR GASOLINE B (For heavy-duty motors).

1. To be high-grade, refined, and de-odorized gasoline, free from all impurities.
2. When distilled in an Engler apparatus, applying 100 cc. at the rate of 10 cc. per minute, it must show the following:
   (*a*) The boiling point must not be above 180° F.
   (*b*) One hundred per cent. must distill over below 310° F. Not less than 98 per cent. should actually be recovered, and the

distillation should be driven to the "end point," which is indicated by the appearance of white vapors in the flask, and immediately discontinued.

As a striking example of the irrelevancy of specific gravity as a criterion for the actual use of gasoline products, there is given below a comparative distillation test between two naphthas of different origin, both of which will of course give equally good results in any motor, but one of which would be rejected by most of the present specifications on account of its low specific gravity.

COMPARATIVE DISTILLATION TEST.

Test No.	1220.	1226.
Specific gravity	0.6865	0.7595
Baumé "	74.7	54.8
DISTILLATION.		
Boiling Point,	120° F.	140° F.
10 per cent. over at	140 "	170 "
20 " " " "	148 "	179 "
30 " " " "	156 "	186 "
40 " " " "	166 "	192 "
50 " " " "	176 "	198 "
60 " " " "	186 "	204 "
70 " " " "	196 "	210 "
80 " " " "	210 "	220 "
90 " " " "	240 "	234 "
95 " " " "	270 " (end)	254 "
98 " " " "	—	270 "

A striking example which may be cited is that of the United States Navy. They formerly had specified only specific gravity for naphtha for their motor boats and launches, and soon were utterly handicapped in purchasing this product in various parts of the world. For instance, while they could easily obtain a product of 70° Baumé specific gravity on the Eastern coast, this was an impossibility on the Western coast and in other countries, because the Pacific and other western oils are very much heavier than Pennsylvania oils, although the gasoline and naphtha products obtained from them are equally volatile and perhaps more useful.

The volatility of two gasolines being equal, preference might well be given to the heavier one, as it has been shown recently that gasolines which, for equal volatility, have a higher percentage of carbon, are the most efficient, because they give a stronger

expansion stroke. This, of course, is based on thermo-chemical conditions, the details of which are precluded by the limitations of this paper. At any rate, it is a fact that a purchaser who buys gasoline by specific gravity alone, not only unnecessarily narrows the source of supply (which of course raises the purchase price), but frequently deprives himself of the better product.

Naphtha for Solvents.—Such cases where gasoline and naphtha products are used for solvents can generally be divided into two classes:

1. For extraction purposes, where the solvent is always recovered and is in a continuous process of extracting, evaporating, and condensing.
2. Where the solvent is used as a liquefier or thinner; for instance, in varnish or similar products.

In both cases the main demands of the product will be expressed by the following:

a. It must be a powerful solvent.
b. For varnish, etc., it must be entirely volatile, so that it quickly evaporates from the paint or varnish after its application. This is usually called its "drying power."
c. It must not contain so much gaseous parts that there will be any considerable loss during the process of cutting or thinning.
d. It must not contain any heavy oils of kerosene character whatever, so that when it volatilizes from the dissolved substance, it will leave it in as natural a condition as possible.

As regards solvent properties, it is an established fact that in the case of two oils of equal evaporative qualities, the heavier one will always prove to be the better solvent. As to the question of volatility, while a certain quantity of very light products, and even a small quantity of heavy products, would not have to be taken into consideration in a motor fuel, a different view must be taken in regard to solvents. Here, any amount of light or gaseous products would always be a total loss and a danger, while a certain amount of heavy non-volatile components would seriously interfere with the dissolved goods and change their character considerably.

To buy such products by specific gravity alone is utterly absurd, inasmuch as it really proves nothing.

A specification for such products, therefore, should demand:

a. As close a range of distillation as possible, the limits of which are entirely dependent on the purpose for which the product is required.

b. As heavy a specific gravity as possible in connection with this evaporation test, which will always insure higher solvent characteristics.

Kerosene (*Illuminating Oil*).—This commodity is still largely sold on tests for specific gravity, color, flashing and fire points. The enormous sales which are made on these specifications may serve as an illustration of how stubbornly an old custom will survive. As already stated, the specific gravity designates nothing but the fraction or "cut," to speak with the oil man, of a certain fixed crude oil.

As regards flashing and boiling points, what is the bearing of the flashing point on the value of kerosene? The answer is that it should insure a certain safety when burning in lamps: danger from a petroleum lamp can only occur if the flame turns back into the petroleum basin, by accident or carelessness, and there ignites the vapors which had accumulated in the closed basin. For this reason, if a certain degree of safety is desired, it is no more than logical that one of the numerous closed-cup tests, like the Abel or Elliott, should be applied. This, however, is not generally recognized, as a great many states still stand by the open-cup and the fire tests. Germany has prescribed a minimum flashing point of 21° C. (70° F.) in the Abel tester. Experience in the German Empire, where such things are followed with great thoroughness, has verified that this flashing point is high enough. Nevertheless, a great many American states and cities go so far as to demand a flashing point of 125° F. in the open cup, which is an altogether unnecessary burden on the manufacturer as well as on the customer, who is compelled to pay higher prices to the former. For this reason an endeavor should be made to obtain uniform legislation throughout the United States, regulating the illuminating oil traffic and fixing a minimum standard which should be reasonable. One of the closed testing apparatus (prefer-

ably the Abel tester) should be used, because its manipulation is entirely automatic and eliminates all personal equations.

As regards the open test, this always depends more or less not only on the skill of the operator, but also upon the conditions of the atmosphere, being rendered totally unreliable by the slightest current of air. The test for open flashing point, however, should be retained in such cases where an oil (or any other product like asphalt, varnish, etc.) will be heated in open vessels, to determine to what degree it can safely be heated without ignition. In such a case the open test is an imitation of actual conditions and therefore fully warranted.

Much more important, however, than the question of the safety of a kerosene oil are its burning qualities. These are dependent:

1. On the chemical character of the various hydrocarbons contained in such oil, unsaturated hydrocarbons burning with a darker flame than saturated hydrocarbons.

2. On the capillarity of an oil; that is to say, on its ability to freely and steadily feed through the wick.

3. On its remaining uniform throughout the burning period; that is to say, it should not contain products of destructive distillation or other non-homogeneous components, which, having different capillarity, would separate during the burning period and show a marked change or drop in the burning qualities at different times.

4. On certain impurities, sulphur, or remnants of insufficient refining, which would cause the oil to gum up during the burning, and result in charring the wick and clouding the chimney or otherwise diminishing the luminous properties.

5. On its suitability to burn in a certain lamp, as not all oils will give equally satisfactory results in one and the same construction of lamp.

To insure the above characteristics, kerosene should be valued by:

(*a*) The photometric test. The lamp used in the writer's laboratory is the Marcy lamp, with a flat-wick burner. The results obtained are of course not absolute, but relative; hence it should be demanded that the lamps should be uniform, and what is most important, that their chimneys should be absolutely alike. The main value, however, is not attributed to one reading of that

lamp, but to readings after two, four, eight, and sometimes seventy-two hours. This in conjunction with the individual readings and the total consumption of oil during that time, gives an accurate idea of the value of the kerosene for its burning and, still more important, for its lasting characteristics during the burning period. If this test is performed properly it will cover the first three points mentioned above.

(*b*) The Engler distillation method, to determine the homogeneity of the oil.

SEVENTY-TWO-HOUR BURNING TESTS.

	A	B
Color by tintometer in 18-in. cell	0.50	1.50
Gravity, Baumé	45.5	48.3
Flash, open cup (Deg. Fahr.)	135	145
Fire (Deg. Fahr.)	145	155
Engler Distillation:		
Boiling point (Deg. Cent.)	166	176
Percentage distilled at 200° C.	54	23
" " " 250° C.	95	82
" " " 270° C.	98	—
" " " 300° C.	—	96
Weight at start, grams	2875	2559
Candle power at start	6.25	6.15
Grams burned during first 24 hours	495	465
Candle power after 24 hours	6.30	5.86
Grams burned during second 24 hours	495	407
Candle power after 48 hours	6.15	5.00
Grams burned during third 24 hours	439	322
Candle power after 72 hours	5.82	2.5
Grams burned in 72 hours	1429	1194
Average per hour, grams	19.84	16.58

A list of tests taken on different oils is given above, which will serve as an illustration of how an actual valuation of kerosene can be determined by following these methods, and shows, again, that judging by specific gravity alone, the better oil would have been condemned.

Lately there have been a great many tests suggested for the determination of impurities, unsaturated hydrocarbons, sulphonic acids, etc., but it is always preferable to have simple specifications, covering only such points the value of which is beyond all doubt.

Lubricating Oils.—Up to the present time lubrication has been accomplished under conditions which did not, as a rule, affect the lubricant chemically; in all sliding parts of steam or other engines, the temperature of which is not much above the ordinary, an oil acts practically the same as it does when tested at the temperature of the laboratory. For this reason, since the development of the steam engine and other mechanical power, *physical* tests have been the only ones used in judging lubricating oils, and their chemical characteristics were either neglected or totally disregarded. However, conditions have changed within the past few years and will very likely change more in time to come. The combustion engine on the one hand, and the steam turbine on the other, are rapidly gaining the field; and the high-power reciprocating engines, especially marine types, are being equipped with the forced feed system of lubrication. In all of these types of power-generating machines, conditions are different from those in old reciprocating engines. In the case of combustion engines the oil is exposed to such high temperatures that it must necessarily undergo chemical changes during its use, and in the case of steam turbines, the oil is constantly exposed to such high speed (and therefore high intramolecular friction) that it will be chemically taxed during its use. It is a fact well-known to engineers that an oil which has been repeatedly used under such conditions cannot be used over again to advantage, although its viscosity may be the same or higher after repeated use as it was before. Nevertheless, this fact has not been considered in present specifications, which call simply for physical tests, such as viscosity, cold test, flashing point, etc.

The general desire, though little expressed as yet, drifts toward such lubricants which will stand up under the new conditions, and there is a general tendency in the engineering world to bring more light on this matter. Of course, mechanical engineers are handicapped by their lack of knowledge of oil matters, and therefore their endeavors toward finding new means and ways of apprizing an oil are very rudimentary and give something of the impression of helplessness. One man judges a turbine oil by the extent of discoloration which it suffers under a certain heat; another, by the amount of residual carbon which is left after evaporation under certain conditions; and still another, by the

degree to which it separates from water when shaken with the same for a certain length of time. A combination of all these tests will reveal that such oils which do not stand up *are either insufficiently refined or contain traces of vigorous and incisive chemical treatment.* These are often sodium salts of high molecular organic acids, and therefore have a soapy character. Especially in the case of oils of heavy character, which act as better solvents, it has frequently been observed that they retain such traces more stubbornly than others, and in consequence a wrong prejudice has developed against heavy lubricating oils.

While these conditions were not especially dangerous on the sliding parts of a comparatively low-power steam engine, it seems that such impurities have a much stronger influence than might be expected from their percentage.

In a combustion engine the oil is not only constantly exposed to an astounding speed and friction, but also to heat estimated between 1800° and 2500° F. Both of these influences tend to form substances rich in carbon, either by decomposition or polymerisation. Oils such as described above deposit "carbon"* in the cylinders and also start corrosion on the cylinders; the space between the sparking plugs becomes clogged, thus rendering ignition impossible, and causing no end of trouble in the running of the machine. An oil, when applied to such an engine, will be divided into two parts, one which works into the upper part of the cylinder above the piston, and one which will flow back into the oil chamber below the piston; the part which comes into the cylinder is subjected to a tremendous heat, and the part which runs back, to high friction and also some heat. In both cases the oil is greatly taxed *chemically*, not merely physically. Of an ideal oil, that part which comes into the cylinder should burn up completely without residuum, and the part which runs back should not form any asphalt or gum.

For turbines, although upon first sight their principle seems to be very different from that of combustion engines, the demand happens to make for the same type of oils, for the following reason: A minute amount of the above-mentioned impurities or

* Such deposits have been frequently examined in the author's laboratory and consist only partly of carbon, the balance being mineral matter, they are always caused by the gradual accumulation of organic salts.

soapy matters contained in an oil will create a certain emulsifying tendency in the oil and hold water in suspension for a very long while after mixing. This, of course, is decidedly undesirable for turbine conditions; and the fact that this soapy matter also causes discoloration by heating is undoubtedly the reason why some turbine engineers propose a heating test of 450° F. There is no apparent reason why a turbine oil should be heated to such an extent; yet it has been found that oils which stand up under this heat make good turbine oils, whereas others fall down. The turbine engineers who devised this test were not at all misguided by their experience, but simply did not know the ultimate cause. The same test and demand is now being made for spindle oils, evidently for the same reasons.

After all is said, it is obvious enough that the determination of specific gravity, viscosity and flashing point have sunk into total insignificance in the testing of lubricating oils, and are no help to the consumer of to-day. While it was formerly considered necessary that an automobile cylinder oil be high in body (likely from an unjustified analogy with a steam cylinder oil), one recognizes to-day that in temperatures of 1800° to 2000° F., the viscosity of all oils is nearly the same, and that hence a very light oil is much preferable. But what can a difference of 50° F. in flashing point amount to at such heats? Whether an oil flashes at 400° or 450° F. is certainly irrelevant if it is exposed to 1800°. But yet there is hardly a specification for automobile cylinder oil which does not demand a high flashing point. It is an admitted, though a not often expressed fact, that the purchaser of lubricating oils is practically helpless and at the mercy of the oil manufacturer, as none of these tests will protect him against inferior deliveries.

For the valuation of a lubricating oil in regard to its use for the above-named classes of machinery, it is not so much a question of what the oil is at the time of delivery, *but what it will be after having been in use for a certain time.*

The greatest handicap thus far for valuing a lubricating oil for these purposes has been that the above-mentioned impurities are contained in such minute quantities that by our average methods of testing they could not be detected. Furthermore, they consist of substances which under certain conditions of heating or friction will ultimately form asphalt, which is not

discernible in the fresh product. R. Kissling was one of the first to introduce a method of analysis which will permit the determination of such substances. This method consists of heating lubricating oils for fifty hours and noting the precipitable asphaltic and tarry matters after that time. It has been further developed in the writer's laboratory, and it can be stated that it enables us now to determine the actual value of a lubricating oil much better than any other way.

Without going into a detailed description of these methods, I would say that their basic principles are as follows:

1. Heating the oil at a certain fixed temperature for a certain number of hours.
2. Precipitating the asphalt formed by means of petrol ether or ether alcohol.
3. Determining the so-called tar or coke value in the oils before and after heating by means of caustic soda and benzol.
4. Determining the change in fluidity by a quantitative method.
5. Emulsion test of oil with water at various temperatures.

We could also mention new methods for the valuation of gas oils, fuel oils, and what is of great significance for itself, asphalts, but discussion of these topics will have to be waived. All that may be said here is that in devising specifications for any product, we should never lose sight of the necessity that our tests should represent actual values, and mean something to both the consumer and the manufacturer. If gasoline is tested, the tests should tell something about its efficiency in motors; if gas oil is tested, figures should be given describing its gas-making value, etc.

Nowhere has there been more abuse by meaningless figures than in the petroleum industry, and in fact in all bituminous products, and it is the writer's desire that the time shall come when this condition shall cease. It is here, like in a great many other things of life, that before new seeds can be planted the soil must be freed from the weeds. Thus, if the above remarks shall cause a fertile discussion of these matters and result in some progress and light in these regions, the writer's hopes for it are amply realized.

DISCUSSION.

Mr. Smith. MR. H. E. SMITH.—In railroad signal service it is very common to use a lamp which burns for a week without trimming or turning up the wick, or any kind of adjustment. Of course a very high grade of oil is required for this purpose. So far as I am aware, most chemists have not been able to make any tests that would determine the value of a new and unknown oil, except an actual burning test. Of course we can assume certain properties if we know the origin of the crude oil from which it was made, but I should like to ask Mr. Sommer if the tests which have been outlined would enable us to pass upon an entirely unknown oil for the purpose of signaling.

Mr. Sommer. MR. ALBERT SOMMER.—I have done a great deal of work with railroad signal lamps. They are burning practically constantly in our laboratory. Oil "A" has been giving especially good service and so far as we can judge by our experience, these tests, particularly the distillation test, would give a very good idea of its efficiency in actual service. I do not want to go into details here, but I can say now that if an oil does not give a good distillation test it is possible that it contains products of cracking distillation. Almost any oil which will char the wick will show a poor Engler distillation.

Mr. Force. MR. H. J. FORCE.—I should like to ask Mr. Sommer if that "A" oil is Pennsylvania oil, or Western oil.

Mr. Sommer. MR. SOMMER.—All those oils that come from Mid-Continental or Southern fields have a certain characteristic, that is, volatility. The "B" oil is Pennsylvania oil.

Mr Force. MR. FORCE.—We tried a number of Western samples for use in our signal lamps, and we found it utterly impossible to keep them burning any longer than 48 hours. We have yet to find one that will stand up or give satisfactory results for semaphores. I should like to know how we can test out an oil chemically, and be sure that it will give the service which we want it to give.

MR. SOMMER.—I shall be glad to name to the gentleman an oil made from a Western crude which burns 120 hours. No oils will give good results unless the soaps are taken out. The Western oils have to be treated differently from Pennsylvania oils, and the reason why the first Western oils coming on the market showed up poorly was that they were manufactured like Pennsylvania stocks. **Mr. Sommer.**

FUEL INVESTIGATIONS, UNITED STATES GEOLOGICAL SURVEY: PROGRESS DURING THE YEAR ENDING JUNE 30, 1910.

By J. A. Holmes.

An event having a most marked influence on the conduct of fuel investigations for the Government during the past year, and one the effect of which will be felt for several years to come, was the reduction of the appropriation for these investigations from $250,000, the sum appropriated for several years previous, to $100,000 for the fiscal year ending June 30, 1910. A still more important event concerning the fuel and mine explosion investigations of the Geological Survey during the year ending June 30, 1910, has been the enactment on May 16, 1910, of legislation creating a bureau of mines in the Department of the Interior, to which bureau these investigations are transferred from the Geological Survey. The effect of this legislation is to supply for the first time an organic law basis for these investigations, which have heretofore had no other authorization than that of a yearly appropriation bill.

During the year the following bulletins were published, embodying results of investigations or tests of fuel:

B 382. The Effect of Oxygen in Coal. By David White.

B 392. Commercial Deductions from Comparisons of Gasoline and Alcohol Tests on Internal-Combustion Engines. By R. M. Strong.

B 393. Incidental Problems in Gas-Producer Tests. By R. H. Fernald and others.

B 402. The Utilization of Fuel in Locomotive Practice. By W. F. M. Goss.

B 403. Comparative Tests of Briquetted and Raw Coal on a Water-Tube Boiler. By W. T. Ray and Henry Kreisinger.

B 412. Tests of Run-of-Mine and Briquetted Coal in a Locomotive Boiler. By W. T. Ray and Henry Kreisinger.

B 416. Recent Development of the Producer-Gas Power Plant in the United States. By R. H. Fernald.

B 428. The Purchase of Coal by the Government under Specifications. By George S. Pope.

In addition to the publication of the above bulletins, the following have been prepared and will probably be published by the Bureau of Mines shortly after its organization, July 1, 1910:

The Volatile Matter of Coal. By H. C. Porter and F. K. Ovitz.

North Dakota Lignite as a Fuel for Boilers. By D. T. Randall and Henry Kreisinger.

The Flow of Heat through Furnace Walls. By W. T. Ray and Henry Kreisinger.

Rate of Formation of Carbon Monoxide from Carbon Dioxide and Carbon at High Temperatures, and its Relation to the Formation of Water Gas. By J. K. Clement and L. H. Adams.

Résumé of Steaming Tests, 1904 to 1909. By L. P. Breckenridge and Henry Kreisinger.

The Coking Industry of the United States as Related to the Foundry. By Richard Moldenke.

Mine Sampling and Coal Analyses, 1904 to 1910. By N. W. Lord, J. S. Burrows, G. S. Pope, A. C. Fieldner, and M. R. Campbell.

Producer-Gas Tests, 1905 to 1909. By R. H. Fernald and C. D. Smith.

Washing and Coking Tests at Denver. By A. W. Belden and G. R. Delamater.

Coals for Illuminating-Gas Tests. By A. H. White and Perry Barker.

Petroleum Combustion. By Irving C. Allen.

The Uses and Value of Peat. By C. A. Davis.

European Gas-Producer Power Plants. By R. H. Fernald.

Lignite Briquetting Tests. By C. H. Wright.

Heat Transmission through Boilers. By W. T. Ray and Henry Kreisinger.

As a result of the reduction of appropriation from $250,000 to $100,000 per annum, it was necessary to greatly curtail the operations of fuel-testing. In point of fact, the demand for routine tests of coal purchased by the Government at several hundred public buildings throughout the United States, including the inspection and analysis of these fuels to determine whether or not they were in accordance with contract, absorbed more than one half of the appropriation, leaving available comparatively little with which to make examinations or research investigations having in view more efficient use of the fuel supplies of the Government.

Early in the year it was found necessary to take mine samples

on behalf of the Navy Department and the Panama Railroad Company from several hundred mines in Pennsylvania, Maryland and West Virginia from which steaming coals reach the Atlantic seaboard; in connection with which sampling the mining conditions and methods of preparing the coal for market were carefully studied, and proximate and ultimate analyses of the coal were made. A little later the work was extended to the steaming coals reaching the Pacific seaboard from Utah, Montana, Oregon, Washington, and British Columbia. The result of these examinations and analyses has been to place in the possession of the government purchasing officers a vast amount of detailed information relative to the capacity of the various mines for furnishing coals of the various grades, and the quality of such coals.

Early in the present year the testing under steam boiler of the coals purchased by the Quartermaster's Department of the Army was transferred to the Geological Survey, and later, the mine sampling and inspection of this coal was turned over to the Survey and, after July 1, to the Bureau of Mines. In addition to other government bureaus or offices for which sampling and testing of coal were conducted, this work was extended in part to the Revenue Cutter Service, to the Navy Department, to the various arsenals and navy yards, the Indian agencies and schools, soldiers' homes, etc.

As indicating the extent of this work, over 6,000 samples of coal have been taken by the inspectors of the Survey during the past year, requiring analytical work in the chemical laboratory, as the basis for settlement of coal purchases, and involving nearly 40,000 analytical determinations. As showing the efficiency of this organization, though the work done increased 260 per cent. over the previous year, the increase in force was but 190 per cent. This work has resulted in the introduction of cheaper grades of coal, including bituminous coals and anthracite pea or buckwheat, in place of the higher grade semi-anthracite and large size anthracite coals.

The study of the distribution and quality of the petroleum found in the United States was continued. Analyses, calorific determinations, and fractionation distillations were made of several hundred oils from California, and a number of type oils and natural gases were analyzed and tested from other oil and gas

fields. Based on these data, modifications and specifications for fuel oils have been prepared for a number of the bureaus of the War and Navy Departments and of other Government departments, by Mr. Irving C. Allen.

Dr. Horace C. Porter has continued throughout the year laboratory and field work connected with the study of the effects of storing coal in air and under fresh and salt water, and the related problems of the distillates from coal and the causes and possible means of preventing spontaneous combustion. Boxes and barrels of coal, properly numbered, and to be removed at intervals of three months, have been placed under water at the navy yards at Portsmouth, N. H., in salt water at Norfolk, Va., in brackish water, and near Key West, Fla., in semi-tropic salt water; also in open air and under cover at each of these points. The same type of coal has also been placed in storage under fresh water, in open air, and under cover, at the Pittsburg testing station, and periodical examinations and analyses of the coal are made.

Dr. J. C. W. Frazer has been engaged in extending his investigations as to the solubility of the hydrocarbons in coal, and in addition, has taken up laboratory studies relating to products of combustion in the special furnace, and to the explosibility of coal dust and the distillation of explosive gas from coal.

Little work has been done during the past year in the way of steaming tests in large boilers. A considerable number of tests have been made on the smaller house-heating boilers, under Mr. S. B. Flagg, but the energy of the sections charged with this class of investigation was chiefly devoted in the past year to studies conducted under the direction of Mr. Henry Kreisinger on the special combustion furnace. The main object of these experiments, which were made in an unusually long and specially designed furnace, was to solve problems in physical chemistry with a view to ascertaining the relation between the amount of volatile combustible driven from the coal and the combustion spaces necessary to burn it completely. Our best steaming coals vary from 15 to 45 per cent. of fixed combustible. The larger part of the latter is burned on the grate, but the volatile combustible must be burned in the combustion space, and for its complete combustion requires mixing with a proper volume of oxygen. The length of

time this mixture remains in the combustion space, and the extent of this space, are the controlling factors.

During the year but little work has been done in connection with large scale producer-gas tests. A study was made of the methods of operating gas-producer plants in various portions of the United States and in Europe, and the results have been in part published. Plans are in course of preparation for the development of a large laboratory type of gas producer with a view to studying the combustion in producers, the temperatures for most efficient combustion, and the temperature of fusion or slagging of ashes from different coals. This, like the long-combustion-chamber investigation, is a problem in which the fuel engineers and chemists will cooperate, and which it is believed will throw important light upon the temperatures and rates of combustion necessary to produce the most efficient results in gas producers.

As with the large scale steaming and gas-producer tests, so with the coal briquetting tests; little has been done because of the great reduction in the amount of money available. Nevertheless, a large amount of laboratory work concerning problems of briquetting has been in progress, including tests upon a hand-briquetting press. In addition, an extended series of tests of briquetting lignite on the German briquetting machine imported by the Geological Survey were conducted on several carloads of lignite from Texas, California and North Dakota. In these tests considerable success was achieved in briquetting lignite without binder. Combustion tests in house-heating boilers, gas producers, and domestic furnaces were made, both on the raw and on the briquetted lignite. The results of these investigations are in course of publication.

THE FOREST PRODUCTS LABORATORY: ITS PURPOSE AND WORK.

By McGarvey Cline.

America is distinctly a wood-using country; the per capita consumption of forest products is much greater than that of any other civilized nation. In 1907 the production of forest products reached a climax; during that year not less than twenty billion cubic feet of wood were used, with a total value at the point of production of approximately $1,280,000,000. The kinds of material making up this enormous quantity, and the relative value and amount of each form consumed, are shown in the following table:

Annual Wood Consumption in the United States.

	Forest Material Required, in Millions of Cubic Feet.	Value at Point of Production.
Lumber, lath and shingles	9,200	$750,000,000
Firewood	7,000	250,000,000
Poles, posts and rails	1,000	100,000,000
Hewed cross-ties	1,450	60,000,000
Cooperage stock	350	35,000,000
Pulpwood	350	20,000,000
Round mine timbers	200	10,000,000

The manufacture of all the materials mentioned in the table, with the possible exception of firewood, is associated with enormous waste, much of which is unavoidable under existing economic conditions. Some idea of the magnitude of this waste may be had from the consideration of that associated with the manufacture of lumber.

It is estimated, from the results of experiments made by the Forest Service, that 25 per cent. of the volume of trees cut for lumber is left in the woods in the form of tops, stumps, and culled logs. Of the logs that reach the sawmill, 22 per cent. is lost in the form of slabs, trimmings, edgings, etc., 14 per cent. in the form of sawdust, and 13 per cent. in bark. The production

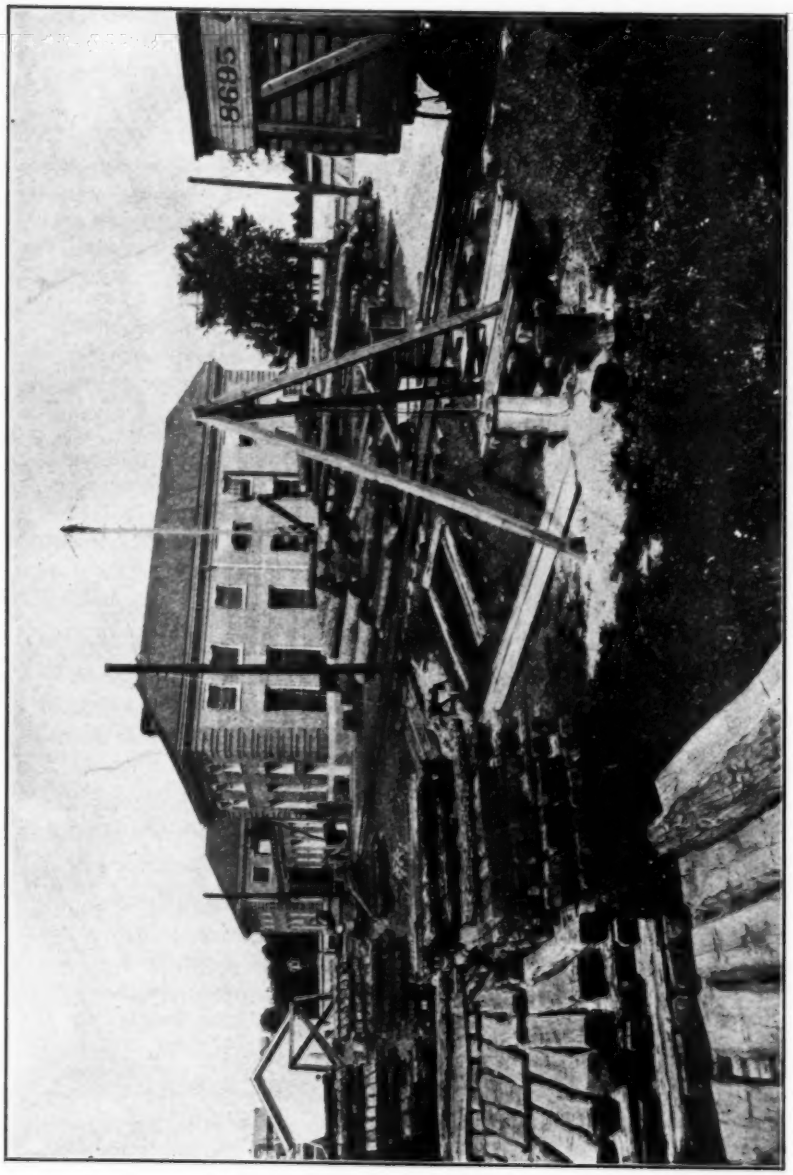


FIG. 1.—General View of Laboratory and Storage Yards.

of lumber in 1907 was approximately forty billion board feet or 3,355,000,000 cubic feet of sawed product. Applying the percentages given above, we obtain the following estimate, in which the items are expressed both in millions of cubic feet and in the percentage of the total amount of wood cut for the production of lumber:

	Millions of Cubic Feet.	Per Cent.
1. Total wood cut for lumber	8,800	100.0
2. Tops, stumps, culled logs	2,200	25.0
3. Saw logs	6,600	75.0
4. Lumber	3,355	38.2
5. Slabs, trimmings, etc	1,450	16.5
6. Sawdust	925	10.5
7. Bark	860	9.8

Items 2, 5, 6 and 7, aggregating approximately 60 per cent. of the total wood cut, may be termed wastes. It is to be remembered, of course, that some of Item 2 is used for firewood, and that a considerable part of Items 5, 6 and 7 is used for fuel in milling operations and for other minor purposes. But even allowing for such utilization, it is estimated that in 1907 four hundred and fifty million cubic feet of slabs and trimmings and ninety-two million cubic feet of sawdust, as well as enormous quantities of bark, tops, and stumps, were absolutely wasted.

After the products of the forest are put into commercial use, they are subjected to great waste due principally to the ravages of decay, fire, insects, and marine borers. It is estimated that these agencies destroy, approximately, seven hundred and forty million cubic feet of wood per annum. Further wastes of considerable magnitude are encountered in seasoning and in manufacturing lumber into the numerous articles with which we are already familiar.

This review, although brief and inadequate, indicates a condition of affairs which immediately suggests the following problems:

1. Can wood substances now being wasted be profitably utilized?
2. Can the present methods of seasoning and handling forest products, now employed by the great wood-using industries, be improved so as to involve less waste?

3. Can the serviceable life of the timber in use be lengthened?
4. Are there satisfactory substitutes among American woods for those now becoming scarce?
5. To what extent can other materials be advantageously substituted for wood?

The purpose of the Forest Products Laboratory is to study these problems and to cooperate with the lumbering and wood-

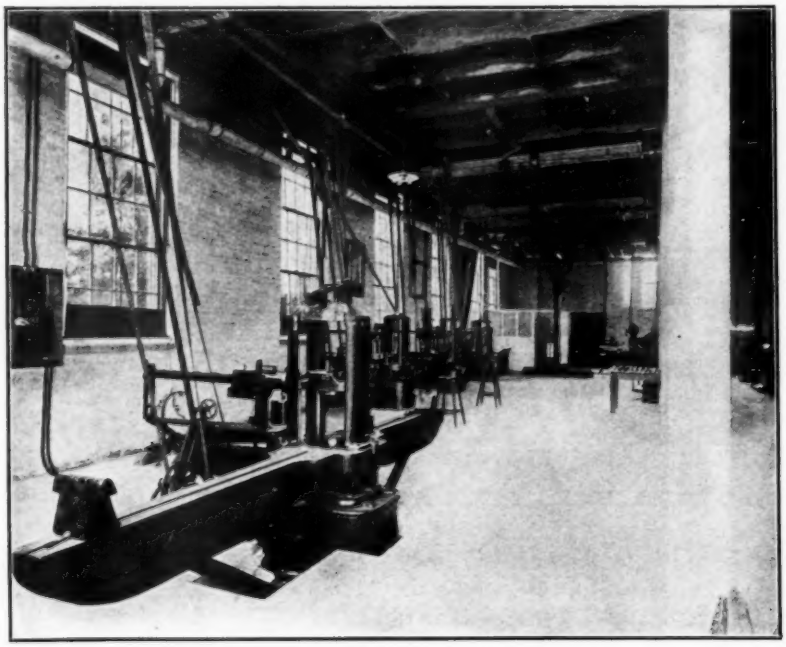


FIG. 2.—View of Timber Testing Laboratory, showing Universal Testing Machine in foreground, and in the background Machine Tools and Impact Machine.

using industries in every way possible to bring about greater economy in the use of wood.

The Forest Products Laboratory is operated by the Forest Service in cooperation with the University of Wisconsin; the University furnishes, without cost to the Service, the buildings and yard space needed, and also the heat, light, water, gas and power (both steam and electric), required for the satisfactory operation

of the laboratory. The Forest Service employs the entire staff, furnishes all equipment, and bears all other operating expenses. The laboratory staff cooperates with the university faculty in giving courses of lectures on forestry and the use of forest products, but aside from such lectures, the staff take no part in the academic work of the university.

For the purpose of administration, the work of the laboratory is divided into projects. A project may be defined as a series of tests or experiments conducted:

(*a*) For the purpose of investigating problems in experimental research;

(*b*) To verify experimental results on a commercial scale;

(*c*) To assist outside parties in the application of principles and processes of recognized commercial value with which the Service is thoroughly familiar.

Most of the work conducted in the laboratory is of the first class, but an important part of the work consists of projects of the last two classes. These latter projects are usually conducted at some commercial plant in cooperation with the company interested in the work, the expenses of the work being borne in part by the cooperating company. The Service has done much in this way to stimulate commercial interest in efforts to secure economy in the use of forest products.

The technical work of the laboratory is divided into six sections, which will now be described.

1. *Timber Physics.*—The section of timber physics studies the structure and physical properties of wood, and the manner in which these properties are affected by different methods of drying and handling. The principal lines of work under way at present are:

(*a*) The microscopic examination of American woods for the purpose of developing a key to their identification, based solely upon the structure of the wood;

(*b*) Experiments to determine the heat conductivity and other heat constants for the principal commercial timbers; in the kiln-drying of lumber and in the treatment of woods with preservatives, it is often important to know how much heat is required and how long it takes to heat wood to a given temperature;

(*c*) Experimental study of different methods of drying wood.

This laboratory is equipped with:

1. Microscopes, microtomes, and other apparatus required for the most careful microscopic work;
2. Apparatus for taking microphotographs;

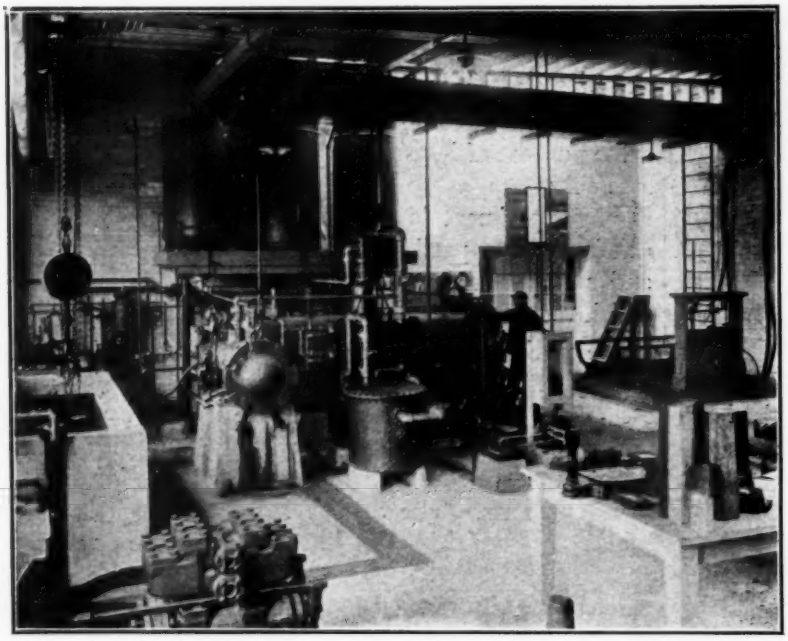


FIG. 3.—Wood Preservation Laboratory, showing Measuring Tanks, Treating Cylinders, and on the left Open Tanks used in Treating Wood by Non-Pressure Processes.

3. A cylinder especially designed for the study of the different methods of drying wood, and an experimental dry-kiln;
4. Balances, ovens, calorimeters, and other miscellaneous equipment.

2. *Timber Tests.*—In this section the strength, stiffness, hardness, and other mechanical properties of commercial woods are studied. Tests are also made on woods treated with preservatives and other substances, to determine what effect the treatments have on the mechanical properties of the natural wood. The most important lines of work under way are:

(*a*) Tests on the different commercial woods to determine their relative strength, toughness, hardness, etc. This work is primarily to assist wood users in finding substitutes for woods now becoming scarce;

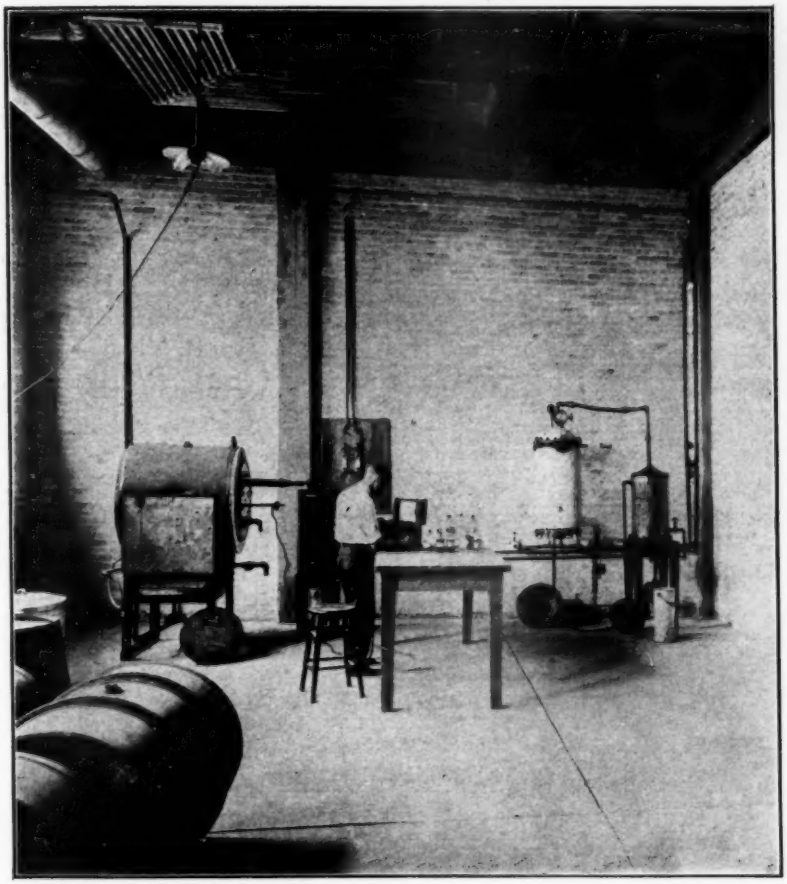


FIG. 4.—Wood Distillation Laboratory, showing on the right Steam Distillation Retort, and on the left Apparatus for Conducting Experiments in Destructive Distillation.

(*b*) Tests to determine the influence of knots, checks, and other defects used in grading structural timbers on their strength and other mechanical properties. These results are of service to architects, engineers, and

lumbermen in forming specifications and grading rules for structural timber;

(*c*) The determination of the mechanical properties of wood impregnated with creosote, zinc chloride, and other preservatives.

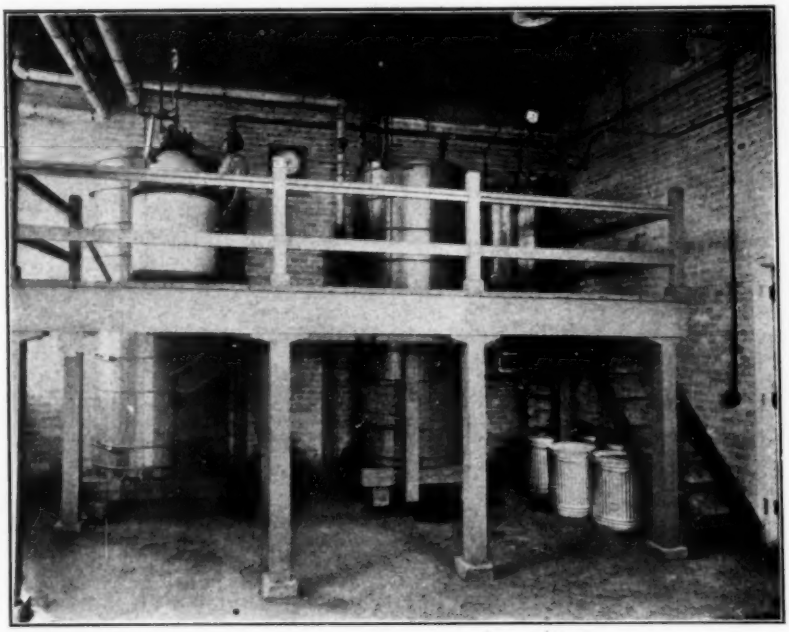


FIG. 5.—Pulp and Paper Digesters and Blow Pits.

The timber-testing laboratory contains the following equipment:

1. One 200,000-lb. extension-base Riehlé testing machine;
2. One 150,000-lb. extension-base Olsen testing machine;
3. Three 30,000-lb. Olsen universal testing machines;
4. One 60,000-in. lb. Riehlé torsion machine;
5. One Dory abrasion machine;
6. One impact-testing machine;
7. Deflectometers, and other instruments used in testing structural materials.

3. *Wood Preservation.*—The impregnation of wood with substances to retard decay and ward off the attack of insects and marine borers has already received much attention. Many processes have been devised, some of which have proved more or

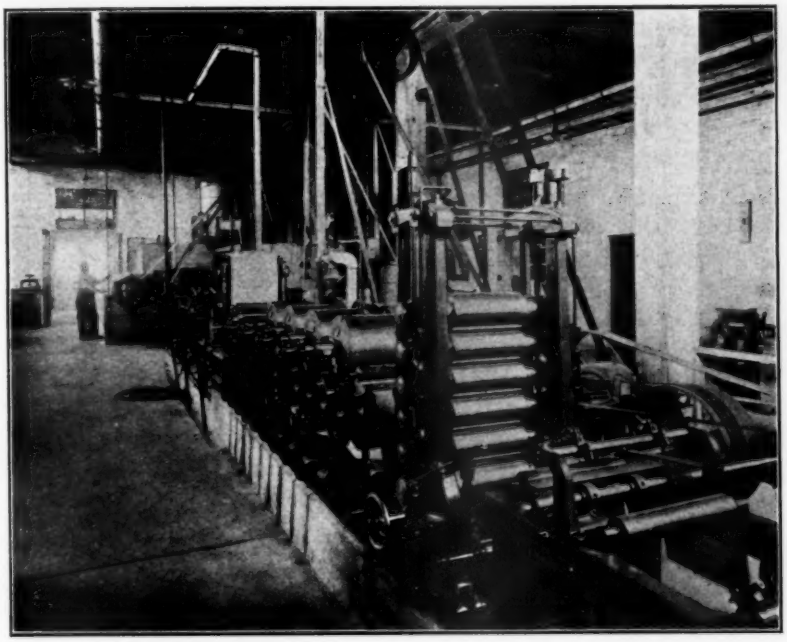


FIG. 6.—Pulp and Paper Laboratory, showing in the foreground the 15-in. Fourdrinier Paper Machine, and in the background Washers, Screens, and other Equipment used in Preparing the Pulp for the Manufacture of Paper.

less successful, and wood preservation is now an industry of considerable importance.

The section of wood preservation studies the problems confronting this industry, which problems may be broadly classified into:

(*a*) Those dealing with the preservatives themselves;
(*b*) Those dealing with the methods of getting the preservatives into the wood.

To study the first class of problems, the laboratory will be provided with a fungus pit which will contain chambers thoroughly inoculated with various wood-destroying fungi. The humidity and temperature will be so regulated that conditions in the pit will be most favorable to the growth of fungi. Woods will be treated with different preservatives and placed in the pit. The efficiency of the preservatives will be judged by their ability to ward off the attack of fungi. These experiments, as well as others of a more refined character, will be carried on.

The second class of problems consists primarily of problems in mechanical engineering, dealing largely with the design and operation of machinery for forcing the required amount of various preservatives into the different species and forms of wood. To study these problems the laboratory is equipped with:

1. One treating cylinder 3½ ft. in diameter and 12 ft long, designed to withstand a working pressure of 300 lbs. per sq. in.;
2. One treating cylinder 1½ ft. in diameter and 3 ft. long, designed to withstand a working pressure of 600 lbs. per sq. in., and two small cylinders for pressures not exceeding 150 lbs. per sq. in.;
3. Open tanks for treating butts of posts and poles.

This apparatus is connected with a system of tanks and force, air and vacuum pumps, for handling and storing the preservatives and for forcing them into the wood.

4. *Wood Distillation.*—The practicability of securing by-products of commercial value from various forms of wood waste is the basic problem of the section of wood distillation. The work naturally divides itself into:

(*a*) Experiments to determine what products and how much of them can be secured from different woods. Alcohol, turpentine, wood creosote, and acetates are at present the products of the greatest commercial importance;

(*b*) The design and operation of machinery best adapted to the production of those products having the greatest value;

(*c*) The refining of the crude products.

The species which will be first studied are Southern pine, Douglas fir, Norway pine, and other resinous woods. It is already known what products can be secured from these woods, but there is great room for improvement in the methods of producing and refining them. The distillation of different hard woods will also be studied. This work offers interesting possibilities for the utiliza-

FIG. 7.—Chemical Laboratory.

tion of slabs, sawdust, stumps, and other forms of mill and forest wastes.

The wood distillation laboratory is equipped with:

1. One steam distillation and extraction retort;
2. One oil-jacketed destructive distillation retort;
3. One three-product continuous refining still and accessory apparatus.

5. *Wood Pulp.*—The section of wood pulp is concerned chiefly with the problems of the pulp and paper industry. It will also

investigate the practicability of using mill and forest wastes in the manufacture of fiber products.

This laboratory is a miniature pulp and paper mill equipped as follows:

1. One 30-lb. sulphite digester;
2. One 30-lb. soda digester;
3. An acid-making system;
4. Experimental grinder for the manufacture of ground-wood pulp;
5. One beating engine;
6. One 6-plate screen;
7. A knuckle-joint power press;
8. A Fourdrinier paper machine which manufactures a continuous sheet of paper 15 ins. wide;
9. Drums, washers, agitators, tanks, and other accessory apparatus for testing pulp and paper.

The problems which will be first studied are:

(*a*) Methods of making ground-wood pulp for the purpose of determining whether or not commercial pulp can be made from species other than spruce;

(*b*) The practicability of treating different woods with the sulphite and soda processes;

(*c*) The quality of paper which can be made from different grades of the various sulphite, soda, and ground-wood fibers;

(*d*) The practicability of using different forms of wood waste for the manufacture of paper pulp and other fiber products.

6. *Chemistry.*—The section of chemistry studies the chemical property of wood and the products secured from them, also the properties of preservatives and other materials used in the treatment of wood. The purposes of the work are:

1. To find uses for products at present having little or no commercial value;
2. To secure data upon which to base commercial specifications for wood products, wood preservatives, and other chemicals used in the treatment of wood;

3. To study chemical problems that come up in connection with the work of the other sections.

The principal lines of investigation at present under way are:

(*a*) The analysis and grading of commercial creosotes;
(*b*) The analysis and grading of wood turpentines;
(*c*) Methods of analyzing treated wood to determine the kind and quality of preservative in it.

In addition to the equipment already listed, the laboratory is provided with a well-equipped wood-working shop and machine shop.

THE SCLEROSCOPE.

By Albert F. Shore.

There are several methods in use for testing hardness. One seeks to measure this property by scratching a polished surface with a diamond point, either under a given pressure so that the variations of depth of the cut indicates the hardness, or by adopting a standard depth of cut for all materials, to be produced by varying weights, in which case the weight required will be the measure of hardness. This machine is called the sclerometer and was originated in Germany nearly a century ago; it was later taken up by Professor Turner, of England, and others. But somehow the results obtained never attracted much attention, for the readings did not appear to indicate certain things that a metallurgical engineer desires to know.

A few decades ago, some of the United States Government officials endeavored to measure the hardness of metals by forcing a point into the specimen under a limited pressure. This method was employed for testing the hardness of raw material—metals when in the unhardened condition. It seems, however, to have attracted little attention until Professor Brinell, of Europe, brought out the ball-test machine, which seeks to measure the hardness by forcing a hardened steel ball into the metal under a known hydraulic pressure—usually about 3,000 kilograms. The ball is generally about $\frac{3}{16}$ in. in diameter. In order to obtain the hardness readings, either the volume of the depression or its diameter must be determined. Sometimes the final index representing the hardness is calculated and the result is independent of the hydraulic pressure; while in other instances a gage is provided which gives the hardness numbers direct when standard pressure is used. There are two ways of expressing the results of this method of testing: on the one hand the figures indicating the hardness are inverse—i. e., they become larger as the metal becomes softer; while on the other hand the figures vary directly with the hardness.

There are a number of different kinds of machines on the Brinell principle which use either weights, hydraulic pressure

applied gradually, or a falling weight which applies the pressure instantaneously. These several instruments are read in different ways, so that as yet there is much confusion; and all of them are limited to testing steels in the unhardened condition, because only a hardened steel ball is used to form the impression. Attempts have been made to obtain hardness readings on the Brinell principle by the use of a diamond point, so that hardened steel might also be tested; but they have met with little success, owing to the minuteness of the impression thus made, and because of the crushing of the diamond.

About 1906 a test was devised in which the magnetic principle was utilized, for it is well known that hardened steel offers more resistance to the magnetic lines of force than soft steel. This method was tried out in England during the last few years, but the difficulties encountered in actual practice finally proved insurmountable. The size or shape of the piece to be tested had everything to do with the readings obtained, while some elements which may be present in soft steel, such as manganese, will cause high hardness readings because they also oppose the magnetic flow.

At about the same time the author discovered that hardened steel, no matter how hard, could be depressed by a very light blow with the ball of a very small steel hammer, and that the hammer had a strong tendency to rebound. What was most interesting was that the surface of the steel could thus be altered, and it occurred to the author that this might be a means of measuring the hardness of hardened steel. Many experiments proved that in very hard steel, such slight impressions could be made, that it was not feasible to measure their diameter or depth; therefore a means was devised to utilize the *recuperative power* of the metal after its elastic limit *had been overcome*. After the elastic limit *was* overcome,—which was entirely feasible in this hard steel, as the first experiment demonstrated,—it became only a matter of reducing the new principle to a scientific basis.

First a $\frac{1}{4}$-in. hardened steel ball was used. It was dropped on the specimen from a height of about 10 ins., within a glass tube, so that it was perfectly free to rebound; for it was the rebound of the striking body which was to finally become the direct indicator of the hardness. The height of the rebound was read against a

graduated scale, just as the height of the mercury column is read in a thermometer. This crude device served the purpose of measuring the comparative hardness of all the softer metals, but it was not capable of discriminating between two hardened steels, for example, one glass-hard and the other spring-tempered. This was due to the form of the falling weight, for the ball has a surface which is much too large for its weight if dropped from the small height considered feasible in a measuring instrument. A hammer was next produced of cylindrical form, having a considerably reduced striking area and increased weight, so that it could very easily deform the surface of hardened steel. As a result, the rebound was much less; and since the elastic limit was exceeded, it will be clearly seen that such an arrangement must measure the quantitative hardness. This can be shown as follows: If a hardened steel bar is quenched without tempering and tested, the little drop weight will rebound to a given height; while if the same piece is spring-tempered, the weight will rebound considerably less, instead of just the same or more as happens with the ball.

A neat little instrument, which has now come into common use, was finally devised; it was named the scleroscope, from the Greek word σκληρότης, meaning hardness. The essential parts of the instrument consist of an accurate glass tube in front of a graduated scale, and the little drop hammer with a blunt diamond point, which slides freely in the tube, but yet not so freely that it wabbles. In fact, it is close enough that a suction produced by a rubber bulb will readily lift it to the top of the instrument, where it is caught by a suspended hook and held there in readiness for testing. The release is effected by the same bulb, which also, by means of a timing cam, alternately operates air valves, so that when the hammer falls by its own weight, no vacuum whatever is formed above it. By this arrangement tests can be made very rapidly—perhaps thirty tests per minute. The indicator hammer does not remain fixed at the highest point of its rebound, and its position must be noted when it comes to a momentary rest before again falling, although this is not difficult after a few minutes' practice.

Any wonder as to how so small an instrument can measure such a high degree of hardness is easily removed when one considers

that the blow delivered by the drop hammer has an impact pressure of no less than 250 tons per sq. in., so that necessarily it crushes the hardest of steel. It is the crushing and the complete overcoming of resistance to penetration of this metal that constitutes the hardness measure as it is understood at the present time.

In spite of the fact that manufacturers everywhere have availed themselves of the opportunity offered by the wide utility of this method of testing hardness, there are many who, while they use it successfully and have found it indispensable in a variety of ways, are not ready to believe some of the claims of the inventor; while others who are not familiar with it believe that the rebound does not measure true hardness, but elasticity. This conclusion is based on the presence of the rebounding hammer; and it is difficult to prove the contrary to the satisfaction of every one.

As stated above, the readings of the scleroscope are not affected by the springiness of tempered steel, but show that it becomes softer, as we certainly know it must, after drawing the temper more and more. This fact has dispelled the "pure elasticity" idea from the minds of those who are familiar with the matter. There is a very definite relation between the elastic limit and the hardness of metals; in fact, it is so well defined, that if the hardness is known, the elastic limit may readily be found, and manufacturers now regularly provide a comparison index which is of great utility to the "busy man."

To appreciate the value of any of the hardness-testing instruments which recognize this property,—i. e., rigidity and resistance to penetration,—something must be known about the previous treatment of the metals; a lack of such knowledge will often cause erroneous conclusions. If we define hardness as proportional to the resistance to penetration, we should expect that if one metal is harder than another by the hardness test, and the edges of each are knocked together, the softer one will be battered more in each instance; and also, that when the edges are rubbed together, the harder one will cut the softer one in proportion to the difference in hardness. However, such is not always the case, and it is for this reason that some have disagreed with the inventor.

Some of the criticisms based on these phenomena were as follows: that neither the scleroscope nor the ball test (for the two

agree very closely on metals in the same condition) are able to measure all kinds of hardness; again, that when the scleroscope indicates that brass is as hard as iron, other kinds of tests will indicate that iron is much harder than brass, by showing that it is much harder to cut and is also somewhat stronger. It has also been said that the scleroscope measures elastic hardness and will not recognize the hardness found in metals which have a low elasticity. When, however, the several conditions which enter here are known, these criticisms cannot be advanced.

Some of the conditions which must be known if one would measure hardness intelligently are as follows: If two metals are selected whose hardnesses are to be compared by the scleroscope, and which are to be knocked together or pressed together according to Foppl's method, to show whether or not the scleroscope reading is correct, the metals must be in a normal condition; they must not be in a "worked-hard" condition, but just as the heat treatment left them. Metals in this condition must be either in the form of castings or wrought metals in the annealed state; or if steel, there must be no mechanical hardness due to hammering or rolling. The necessity for this is due to the fact that when any of these metals are exposed to pressure,—and it does not matter if one is used as a tool against the other for cutting,—whatever change is caused in them is always due to *pressure* and *this will superharden them*. Thus, when a brass casting and a piece of annealed steel showing exactly the same hardness are knocked together, both will receive an indentation of the same depth, thereby proving that the scleroscope correctly showed them to be of the same hardness. Neither one will cut the other when they are rubbed together, but each will show the same amount of tool wear when worked in the regular way, provided the tool is ground to suit the fiber of each metal.

These conditions have not been observed by those who have disagreed with the claims of the manufacturers of the instrument. It is very easy to explain why one metal which is softer than another will sometimes either batter or cut the harder one. Let us cite an example: Copper when cast shows a basic hardness of about 6, but it may be superhardened to 20 by hammering. If now we select a piece of brass casting showing a hardness of 10 and knock it against the copper having a hardness of 20, the copper will be

indented and cut by the brass which is only half as hard. The reason for this is that the copper, which has been superhardened to its limit, cannot be made harder by further compression, although the hardness of the brass casting may become 30 from compression such as occurs when two metals are forced together; and necessarily the brass must batter and cut the copper. And after all, a comparison of one metal with another according to Foppl's method has absolutely no value unless the condition of the metal is carefully specified.

It has been said that manganese steel is very hard, but the scleroscope was not able to measure the peculiar hardness it has; for although it cannot be machined, it shows a very low reading. Annealed tool steel, for instance, has a hardness of 30 and can very readily be machined, while the manganese steel measuring exactly the same by the scleroscope would have immediately taken the edge off the hardest steel drill. Both the Brinell ball test and the scleroscope show that manganese steel is no harder than is indicated by the readings which are obtained, although it has a very abnormal development of attrition resistance—that is to say, it contains an abrasive which will at once wear off any steel tool which cuts with a scraping action like a drill or a file. There are many who will not be easily convinced on this point, but the accuracy of the explanation is shown by the fact that manganese steel which can absolutely not be drilled, can be cut with the greatest of ease by a cold chisel which is not even up to the standard in hardness. The action of this tool is such as to escape the abrasive effect of the manganese in the steel. This is a very extreme case, but nevertheless all metals have a certain quota of the abrasive element, and unless something is known about this property, one will always be baffled by the hardness readings obtained. In the case of plain carbon steel, having either a high or a low proportion of the abrasive element, the tool wear will increase directly with the hardness. High tungsten steel, when annealed, shows a decided shortage in the abrasive elements and can therefore be machined at a much higher hardness than carbon steel.

In line with these facts, there are other paradoxes which apparently are just as difficult to understand under the present status of this science. Take, for example, a 7-per cent. nickel steel, hardened, and a 1.70-per cent. carbon steel, over-heated and crys-

tallized by quenching. The hardness of both may be only 55 by the scleroscope, yet neither can be filed as much as some steels which have a hardness of 90. The nickel steel referred to is about the toughest material known at this hardness, while the burnt carbon steel, on the contrary, is the brittlest.

Those who are familiar with scleroscope practice know from experience that no matter how tough or brittle a metal may be, if this instrument indicates a low hardness, the specimen can be easily battered with a hammer, although the scleroscope does not always indicate the amount of attrition resistance or wear endurance. This latter property, which may be under the control of the metallurgical chemist to a certain extent, by means of alloying will show with a few experiments a little more about the several methods of testing hardness than is now generally known.

For instance, the sclerometer, which is the diamond scratching machine, would show a high reading on the hardened nickel steel and the crystallized high-carbon steel, and probably also to a certain extent on the manganese steel previously referred to; and thus it would completely mislead a construction engineer who recognizes as hardness the properties of rigidity and resistance to penetration.

The Keep drill test, under the present status of this science, even though confined to the softer metals, can no longer be regarded as even an approximate method for testing hardness. The principal reason is that it will indicate almost absolute hardness in such metals as manganese steel, which to another cutting tool, like a chisel, is not very hard at all. The drill test will indicate false hardness in carbon steel when compared to high tungsten steel, and although both the drill test and the diamond scratch method are cutting devices, it is evident that they will disagree on certain metals. For example, manganese steel contains an abrasive element which is hard enough to destroy the edge of a steel tool but not that of the diamond, so that it is hard to tell just what either one will measure. One thing is apparent, however: although we may not fully understand the diamond scratch method as yet, the drill test actually shows something of the abrasive element in metal of a given hardness, or rather, it shows the tool wear which would occur if that metal were to be worked by steel tools; and from the standpoint of precision, it can measure nothing else.

The diamond scratch method and the drill test, as Professor Turner has shown, will not fully confirm or recognize the hardness readings of the scleroscope on metals which have been hardened by rolling and drawing, for the reason already given—namely, that the cutting action is influenced by the toughness and attrition resistance as well as the physical hardness. In normal metals this property increases in proportion to the hardness; but when the hardness is increased abnormally, as by pressure, the abrasive property does not increase proportionately, and hence the failure of the cutting methods to recognize the good work of the rolling mill.

The author wishes to point out, in connection with measuring hardness, that there is much research work to be done, and that the claims for more than half a dozen different kinds of hardness should be investigated. If there are so many different kinds of hardness, we should know it; and if there is but one kind of hardness, an alleged plurality would tend to mislead.

Viewing the situation from a practical standpoint, there is primordially only one kind of hardness—the tough hardness. This is the one that the engineer must call for, and whenever he specifies a given hardness, it is understood that he is to get the greatest possible toughness with it. Some call this "tough hardness" and some call it "tensile hardness;" while again the term "tensile hardness" has been applied to metals whose tensile strength is increased by cold rolling, when the cutting hardness test failed to recognize the extra hardness. This is apparently wrong.

When hardness is thus produced in the metal, and it deviates from the standard, a variety of names are used to describe the different conditions of the metal. For instance, when the steel is burnt so that its strength is impaired, it is said to be "brittle hard." Elastic hardness, as we have seen, is meaningless. Cutting hardness must sometimes depend on some special properties, such as red hardness in high-speed steel. Otherwise, in so far as this term may be of value, brass will cut hard rubber better than will hard steel. A tool made of babbitt metal will cut lead if it is between two or three times as hard, and annealed steel will cut very soft brass. Abrasive hardness simply exists when a metal is really soft and has an abnormal propensity to resist wear or the

cutting tools. Some speak of static hardness as opposed to dynamic hardness, but there is probably very little in this. Those who have coined these phrases have not satisfactorily explained their meaning.

This plurality of terms, most of which are not clear, is at the present time just as misleading as the hardness measure, regarded from a viewpoint of a *universal standard* (which latter is obviously very urgently needed, since testing for hardness has become so general). In chemistry, we have symbols which are recognized the world over as meaning one and the same thing, while in heat measurements, although there are two or three scales which are different, one can readily be resolved into the other by well-known formulas. The ball-indentation hardness test is read in a different way by almost every maker of this device, and so far as the author knows, there is no way of resolving one into the other. There is therefore no way of resolving scleroscope readings into ball-test readings, broadly considered.

Owing to the fact that calculations are to be made with the ball-test method and that there are so many conditions which enter, upon whose constancy reliable tests depend, it would not be, in its present stage of development, safe to take it as the universal standard for even the soft metals to which it is limited. This condition has been widely recognized and it is perhaps needless to say that since the scleroscope involves no variable factors whatever, and since it is capable of measuring the entire range of hardness, including the most intensely hard steel, it has for more than a year been recognized as the universal standard by those who are familiar with it.

There is another important phase of our subject. It is perhaps needless to point out that there is a general change taking place in specifications for materials used for construction purposes, in which the scleroscope is performing a very prominent part as a constant guide to the engineer. This improvement is noticeable particularly in the smaller details. When there was a general lack of knowledge as to the true meaning of hardness, most designers preferred to be on the safe side in using something that would not be "hard enough to break," and which too often created a preference for a material entirely too soft.

In automobile engineering the very soft iron rivet and the mild-steel bolt have been discarded, and they are now made of a definite hardness. Rivets of course must be softer than bolts at all times, but screws and bolts are heat-treated and must show a spring temper; while even cotter pins, which sometimes are sheared by strains or crystallized by bending several times, are heat-treated to show a low spring temper. A certain hardness standard has been adopted for each.

It will perhaps seem rather early to urge that similar methods be used in civil engineering, particularly in building bridges, but it is nevertheless a fact that a good beginning has already been made by some engineers in this line. The author's own experiments have shown that the shearing resistance of rivets increases quite directly with the hardness increment. Taking, for example, an ordinary rivet, the hardness of which may be 21, as compared to another the hardness of which is 42, it will be found that the one twice as hard has about 95 per cent. more resistance to shear. A hardness of 42, by the way, is less than that of a number of steels when they are annealed for machining, and I believe that with the proper composition, not losing sight of the condition under which the rivets have to be inserted, hardnesses of 45 to 50 are not too high and are easily possible. If the plates which the rivets join are a little harder than the rivet, which is usually the case, they will act as a sharpened shear under stress and will remain sharp until shearing has been accomplished; while on the other hand, if the rivet is a little harder than the plate, the plate will lose its keen shear edge, so that it would stretch the rivet rather than cut it, in which case a much greater load could be carried. Assuming that the average structural-steel parts have a hardness of from 25 to 35, a rivet showing a hardness of from 40 to 50 would be able to destroy a good part of the keen shearing effect, besides having a much higher elastic limit.

In ordinary work, the scleroscope has formed at last a connecting link between the technical man and the shop man in so far as the hardness measure and its complex meanings are concerned. The technical man, by making experiments or testing samples of products submitted to the purchasing department, can make selections or decisions which are with very little ceremony handed to the draftsman, who then incorporates the figures in his drawing.

The shop man will, by the aid of the scleroscope, be able not only to get out the product mechanically accurate, but in addition, he can have his materials up to a certain specification. The shop manager will refer to the scleroscope scale in the preparation of his requisitions for the purchasing department, while the latter will in turn use the same figures in the specifications of his orders. It does not matter where these orders go, whether abroad or merely to another domestic manufacturer. There is at this time no difficulty whatever in filling these exactly as desired. This system is very commonly employed, and there are any number of guarantees on products depending upon its convenience. Many of these guarantees would have to be recalled if the scleroscope were suddenly non-existent, and many methods of manufacturing would have to be changed.

Finally, it is generally little realized how much depends on the hardness of a metal and to what extent it might be used effectively as a code representing other properties. One of the most important of these is tensile strength. It is not possible to test the tensile strength or elastic limit of finished parts, much as we would like to do, particularly after they have been heat-treated (for in this process they undergo a change which may make every individual part made of a heat of tested steel different from the test piece); but if a sample is heat-treated and tensile tests are made thereon and a given hardness is shown by the scleroscope, it is possible, by using a uniform correct temperature and a like hardness in each piece, to make any number of pieces of the same character of steel which will show the same strength as the test piece. The hardness measure will show any discrepancy due to a variation in temperature, as regards the strength.

Among other data of this nature, the manufacturers of the scleroscope have been able to get out for use in connection with the scleroscope a standard scale of comparative elastic limits, which is remarkably accurate. This elastic-limit scale shows that there is a definite relation between hardness and elastic limit. It may be interesting to mention the fact that compared to the results obtained by the testing machine at Watertown Arsenal, the values of the elastic limit obtained from the scleroscope readings on hardness are somewhat high, while compared to the test made by the drop method to obtain the elastic limits, they are

low. It has also been found that by heat-treating some steels in one way, an elastic limit compared to the Watertown one was obtained, while heat-treating another way to get precisely the same hardness, an elastic limit equal to that shown by the shock method was obtained. Hence, the manufacturer's idea of the elastic-limit scale which occupies a central position, which can be of great convenience to engineers and manufacturers, and which is usually quite as accurate as a metallurgist can commercially fill an order to specification.

GENERAL DISCUSSION ON HARDNESS.

The President. THE PRESIDENT.—There are three gentlemen named to open the discussion: Messrs. A. F. Shore, Bradley Stoughton, and Albert Sauveur. Mr. Shore proposes to open the discussion in the way of receiving and answering questions. He thinks that he has expressed himself already fully in his paper, which I think we will all admit, so that the plan which he proposes is to have those present question him on any points which require clearing up.

This matter of hardness is of course one that interests us all. What Mr. Shore has said I think is very suggestive and instructive.

How comes it that one of two materials seems the harder when subjected to one kind of test, and the other seems the harder when tested by another test? At first sight it seems as if all forms of resistance to distortion were only varying manifestations of the cohesion between the particles of which the material is composed. If this cohesion is greater in material A than in material B, then A ought to resist every attempt to distort it better than B, whether that attempt is by pushing or by pulling, by tension, compression, abrasion, scratching, indentation, or what not. Each and all of these actions proceed essentially by moving adjoining particles of the material away from each other or past each other, and either by a push or by a pull or by both; and the resistance to push or pull certainly ought to be due to and to be measured by the cohesion between the particles of which the material is composed; so that, no matter to what kind of stress a given series of materials is tested, the members of that series ought to stand in the same order in regard to their power to endure the test.

This being the case, we ask how it comes about that chilled cast iron is so much harder than rail steel but so much weaker, and in general that the order in which a given series of materials stands, varies greatly with the kind of test by which we test them. Is this due to defects in our tests, or is it inherent in the nature of materials? Is it to be hoped that any one test, for instance Mr. Shore's, will be able to displace all others?

The President. It seems to me that it is due to the nature of the materials with which we have to deal, and I see two important reasons why different tests must assign different values to any one of a series of materials and, further, why some of these tests are and must remain better as tests for certain industrial purposes and other tests are and must remain better for certain other industrial uses. There may be additional reasons, but two at least stand out prominently. They are first that our materials are all heterogeneous, and that this heterogeneousness has more pronounced effects under certain conditions of testing and use than under others; and second, that they differ greatly in plasticity. Under heterogeneousness I include not only cleavage planes, and other internal planes, etc., which differ in cohesion from the rest of the material, and in general the crystalline structure, but also the conglomerateness or granitic state which all steel has. It may be that, if there were any absolutely homogeneous non-plastic solids, not only composed of a single substance instead of being conglomerates of different substances, but also free from all cleavage, stress, and crystalline structure, they would all stand in the same order whether tested tensilely, transversely, or compressively, by scratching, indentation, or what not. Now the resistance to different kinds of tests is affected differently by these several phases of heterogeneousness and by plasticity; and this, I take it, is one extremely important reason why the order in which a given series of materials stands, varies so greatly when they are examined by different kinds of tests. Furthermore that is, I take it, an essential reason why one material is better for one purpose, a second for another, a third for a third, and so on. Were they all homogeneous and non-plastic, then we might expect the strongest to be the best for nearly all purposes.

As a simple example of the way in which different tests are differently affected by these phases of heterogeneousness, we may take the case of two built-up platforms, A of hardened steel bricks laid dry, and B of wooden bricks well glued together. If tested with a file, platform A is much harder than platform B. If tested by a Turner sclerometer test, i. e., by drawing a plow across them, platform A would be weaker than platform B, because the nose of the plow would easily catch and dislodge the dry-laid hardened steel bricks, whereas the glue would prevent

The President. it from dislodging the wooden bricks of platform B. Evidently the file test addresses itself to the cohesion between the several particles of a given brick, whereas the plow test addresses itself to the adhesion between adjoining bricks. A tensile test would act like the plow test. If I laid hold of the end brick of platform A with a pair of tongs and, pulling horizontally on it, exerted what may be called a tensile stress, I would pull away that end brick with the greatest ease; whereas a like pull on the end brick of the platform B would be resisted by the whole strength of the glue.

Very much in the same way, certain tests applied to our materials address themselves chiefly to the cohesion between what may be called the ultimate particles, whereas other tests address themselves chiefly to the cleavage planes, or to the cement between certain of those ultimate particles. Hence the different order in which different materials stand under different tests. Those materials with great cohesion along their cleavage planes may be well adapted to resist the latter class of tests, even if the cohesion between their ultimate particles is relatively low; on the other hand, those materials which have great cohesion among their ultimate particles, like our dry-laid steel-brick platform, may be well suited to resist the former class of tests, even if their cohesion along their cleavage planes or between the several distinct microscopic constituents which compose them is relatively weak. An emery bag is hard if tested by the thoroughness with which it scratches rust off a steel needle, but very soft if tested by squeezing it between the fingers. A barbed wire boundary fence of soft steel is harder, if tested by plowing my neighbor's cow's hide, than a smooth wire fence of hardened Stubb's steel.

But the point of all this is that what is true of tests is also true of industrial uses. A test ought to be simply an attempt to parallel the proposed conditions of industrial use. Certain conditions of use, those for instance in which there is an enormous number of repetitions or reversals of stress, may demand primarily the absence of internal planes of low cohesion. Other conditions demand the resistance to only a very small number of very severe stresses, each of which must needs cause permanent set; the primary requirement for these may be great plasticity. To take another instance of variation in the mode of application of stress,

here a brake shoe rubs over a chilled car wheel, perhaps addressing itself chiefly to the cohesion between the particles of cementite protruding above the softer surfaces of pearlite which have been rubbed down; there a flat wheel pounds on a rail, and perhaps tests primarily the adhesion between the cementite and the pearlite of that wheel. Each industrial use, like each different kind of test, addresses what is the path of least resistance under its own peculiar conditions. **The President.**

That there are very great differences in the properties needed for the different industrial uses, even when those uses are extremely closely related, is familiar to all of us if we will but refresh our memory. Thus we know as a matter of observation which cannot be gainsaid, that in crushing certain kinds of rock a stamp shoe of cast iron is by far the best that has yet been tried, that it is much better than a shoe of the best anvil steel or of hardened tool steel; whereas for crushing certain other kinds of rock chrome steel, and for others manganese steel, is far better than cast iron.

Note here how slight a variation in the conditions of use requires us to substitute for cast iron, which is perfectly brittle, extremely weak, and excels only in mineralogical hardness, a radically unlike substance, manganese steel, much softer than cast iron, but of extraordinary ductility in view of its hardness. The stress is the same in both cases; the form of the stamp shoe, its weight and fall, and the work which it is to do, these are exactly alike in crushing the two kinds of rock; but the slight difference in the properties of the rock to be crushed in one case gives the extra hardness of cast iron a value which outweighs its weakness and brittleness, and in the other gives the ductility of manganese steel a value which outweighs its relative softness.

Take again the case of a manganese-steel car wheel running on a manganese-steel rail. We know that a manganese-steel rail offers very great resistance to abrasion. Now a manganese-steel car wheel riding on that rail is in apparently the same condition, and there is the same kind and degree both of friction and of pressure on the face of the rail as on the face of the wheel. Therefore, if a manganese-steel rail resists abrasion so well, certainly the manganese-steel car wheel on that rail ought to resist it equally well. The material is almost indestructible by blows, and here you would think you had an ideal material for car wheels; but

The President. to our regret we found that what we thought would prove an ideal material, when put to test proved not to be well fitted for car wheels. Why it should be that a manganese-steel car wheel riding on a rail should wear out relatively fast while the rail made of the same material and subjected to the same stress resists abrasion admirably, we simply do not know.

Now it is for this underlying and essential condition, which in the nature of things must persist forever, that I for one do not believe that it is possible, even if it is conceivable, that any one hardness test ought ever to be the universal one, displacing all others, because of our different tests, present and to come, one will simulate most closely the conditions of one industrial use, and another will simulate most closely the conditions of another. And the special properties needed for one class of industrial uses necessarily differ, and must always continue to differ radically from those needed for certain other industrial uses. And for each industrial purpose we should use the test which is shown by reason, backed by experience, to give the most trustworthy measure of usefulness, including safety, in that particular service.

Of course some one test may have such decided advantages of one kind or another that it will be used to a much greater extent than any other, or that when in doubt we may naturally turn to it. Such an advantage the Shore scleroscope test may prove to have in its extreme simplicity and ease. The further question, then, presses on us: "Do reason and experience show that its indications are trustworthy measures of the usefulness of different materials for many of our important industrial purposes?"

Mr. Howard. MR. J. E. HOWARD.—The subject is a baffling one, and just what is being obtained from the results is perhaps not clearly understood. The most obvious inference is that since, as a rule, the hammer makes a slight indentation in steels, the relative hardness by this method will be influenced by the shape of the stress-deformation curves of the steels just above their elastic limits, and the results modified accordingly. It is of course difficult to make comparisons of the relative hardness of different substances by this method. For example, judging from the rebound of the hammer, a block of paper possesses about the same hardness as one of cast iron. The attention of the speaker has been called to observations in which the hardnesses of a piece of tool steel and an india-rubber eraser were substantially identical on this scale of hardness.

MR. J. H. PARKER.—I have used the Shore instrument for about a year, and I have found some variables which must be taken care of. The glass tube must be perfectly plumb, the surface receiving the hardness impression must be truly normal to the line of impact, and the surface must be properly prepared; that is to say, it must be ground absolutely smooth and must be free from all tool marks—even rough file marks. Also, in determining the hardness of hot-worked materials, the surface decarbonization, which is always present in a more or less marked degree, must be removed in order to obtain the true value. I have come across several cases where unduly low values were found, where by going down only a few thousandths of an inch the correct values could be readily obtained. **Mr. Parker.**

MR. ALBERT F. SHORE.—I think that is very nearly correct, although of course, the condition of the surface should depend upon the hardness of the specimen. The harder the specimen, the smoother the surface should be; but it is never necessary to provide an absolute polish. For hardened steel, an emery wheel which is generally used for grinding small drills, makes the surface sufficiently fine. For unhardened steel, a No. 2 file is satisfactory. Nothing is gained by further polishing. In regard to decarbonization, that is nearly always a characteristic of hot-rolled metals, and it would be unfair to make a test on such a surface. The right procedure is either to file or grind off the surface, or to make the test on the exposed end of the piece. **Mr. Shore.**

MR. J. S. MACGREGOR.—Suppose the material is so hard that it resists the action of the file; as for instance, chrome or case-hardened steel. How should the test be made then? **Mr. Macgregor.**

MR. SHORE.—That does not necessarily indicate the hardness of the metal, assuming that hardness is regarded as resistance to penetration. The diamond point that we use will often penetrate particularly high nickel steels which have been hardened and which will resist the file perfectly and yet exhibit a degree of hardness of only about 55. Again, such steel may be hardened in some different way to about 75, provided the nickel content is as high as 7 per cent. The lower the nickel content, the higher the hardness. Some nickel steels are very tough, although really low in hardness. We found that gears made of this material, showing a hardness of 55 and which could not be filed, will not stand up **Mr. Shore.**

Mr. Shore. in service. If used for clash gears in automobiles, the material will batter.

A Member. A MEMBER.—What is the minimum thickness of a specimen to be used for testing purposes?

Mr. Shore. MR. SHORE.—For very soft material the minimum is about 0.012 in., while for hardened steel, such as safety razor blades, it is 0.006 in. If an individual piece is too thin, tests can be made by piling up to the proper thickness. It is necessary that the pieces should be flat and that they should be properly supported. The thinner a specimen, is the more securely it must, of course, be clamped. The instrument is built in such a way that if it is correctly operated, no error can be made.

Mr. Alford. MR. L. P. ALFORD.—I should like to ask if the instrument will show the presence of temper drawing due to dry grinding, and how it will compare in this respect with the Brinell machine.

Mr. Shore. MR. SHORE.—The Brinell machine cannot be expected to show much here, because the temper drawing is usually only a few thousandths of an inch deep; but the scleroscope easily shows when there is temper drawing.

The President. THE PRESIDENT.—Certain series of comparative tests, in which like series of substances have been tested by the Shore machine and by the Brinell machine under static pressure, have given results which are very closely comparable.

Mr. Douty. MR. D. E. DOUTY.—At the Bureau of Standards we have been carrying on for some months a series of comparative tests by five methods of measuring hardness. The following comparison between results by the scleroscope and by sphere tests according to the Brinell method, may be of interest:

	By Scleroscope.	By Brinell Method (Hardness Numeral).
Tool steel	86.1	641
Silicon steel	33.6	262
Manganese steel	29.5	179
Cast iron, No. 1	33.3	149
Cast iron, No. 2	32.9	172
Bessemer steel	26.6	185
High-carbon steel	37.8	289
Cu. (70) Sn. (30) alloy No. 1	42.4	110
Cu. (80) Sn. (20) alloy No. 2	25.5	101.5
Cu. (90) Sn. (10) alloy No. 3	22.1	94.7
Copper, No. 4	15.0	88.5

THE PRESIDENT.—Mr. Shore's point, that his method does not require so great a thickness of the material under test as the Brinell method, seems to be well taken, and to indicate a distinct advantage for his method where the superficial hardness is of overwhelming importance. But by like reasoning it seems to follow that, for other purposes where the hardness of a considerable thickness, including not only the very surface but a considerable depth below it, is of prime importance, the Brinell indications should be of greater value. **The President.**

As between the Brinell drop and static methods, though the drop method has the advantage of far greater rapidity, it evidently needs precautions to insure constant conditions of inertia, not only in the anvil proper but also in the piece tested. As an example, we made a series of tests and got harmonious results with the Brinell drop machine. Soon afterwards we got another series of results, harmonious among themselves, which did not agree with those of the first series. On investigation, we found that we had not placed the machine at the same spot on the floor, which was a concrete floor on steel beams with concrete filling. Apparently the slight difference in resilience or inertia of different parts of the floor was enough to affect very greatly the results obtained with the Brinell machine.

MR. E. O'C. ACKER.—I understand from Mr. Shore's paper that the results of the hardness tests in general parallel the values of the elastic limit very closely. I should like to ask the following question: Let us assume a 3¼-per cent. nickel steel of about 0.35 per cent. carbon, and temper it so as to get an elastic limit of about 110,000 lbs. per sq. in. With a carbon steel tempered we can get about the same elastic limit. We find that we can machine the nickel steel very readily, and that it can, in fact, be cut with a knife; but we find that the carbon steel of the same elastic limit is very difficult to machine. We also find that if we take a nickel steel and a carbon steel and temper both to obtain the same ultimate tensile strength, the machining qualities agree much better, although the elastic limit of the nickel steel is very much higher than that of the carbon steel. Now, I should like to know what the scleroscope would indicate in the above cases. **Mr. Acker.**

MR. SHORE.—It was stated in the paper that manganese steel, for instance, being as low in hardness as annealed tool steel, **Mr. Shore.**

Mr. Shore. cannot be machined at all. It is not the hardness in this instance which resists the machining, but the abrasion-resisting quality of the metal. Manganese steel cannot be drilled, because a drill cuts with a scraping action, although such steel can be very easily chiseled, as this avoids the abrasion-resisting action of this material. This applies more or less to all metals, and I think to nickel steel. High-carbon steel having the same hardness as high-tungsten steel, can be cut less easily by a drill because in annealed steel carbon affects the abrasion-resisting quality more than tungsten.

The President. THE PRESIDENT.—This brings out the point that I tried to make. In many cases the ease with which a metal may be machined is one of the most important considerations; for instance, as every foundryman knows, a very valuable element in a casting is its machining quality. A hardness test which will not tell us how easily a piece may be machined, while it may be useful for other purposes, is worthless for that particular purpose.

Mr. Furness. MR. RADCLYFFE FURNESS.—I should like to ask Mr. Shore if the scleroscope readings are indicative of the comparative tensile strengths of different kinds of materials, such as nickel steel and nickel-chrome steel.

Mr. Shore. MR. SHORE.—Approximately, provided a certain amount of elongation is developed before fracture. Differences in the readings are indicative of differences in the ultimate strength, although the differences in the elastic limit may not be very great. You cannot measure the elastic limit in hardened carbon steel in any way, because it fractures before the elongation is obtained.

Mr. Furness. MR. FURNESS.—That has not been my experience. I think it will be found that nickel-chrome steel which has been heat-treated, and which has an elastic limit of 230,000 or 240,000 lbs. per sq. in., will test about 62 to 66 upon the scleroscope; while carbon steel that will give about the same scleroscope reading will be much lower in tensile strength and elastic limit. A piece of carbon steel that will test 65 on the scleroscope will elongate sufficiently for determining the elastic limit. I know that a nickel-chrome steel bar which has an elastic limit of 230,000 lbs. per sq. in., will not test over 62 on the scleroscope.

Mr. Shore. MR. SHORE.—Carbon steel with a scleroscope reading of 65 ought to show a certain amount of elongation if it is not crystallized and if it has not been abused in the fire.

MR. FURNESS.—I have never considered it fair to compare steels of two different compositions on the basis of the scleroscope readings, because although they may have the same tensile strength, I have always found the scleroscope readings to be very different. I find that a series of a given composition can be compared very accurately by means of the scleroscope. Therefore I think it is an excellent instrument for comparing metals similar in composition. **Mr. Furness.**

MR. SHORE (*by letter*).—The subject referred to by Mr. Furness is a very live one, for I know that many large manufacturers who maintain testing laboratories are working to show exactly how close the scleroscope hardness is related to the elastic limit. **Mr. Shore.**

I must say that I never heard of an alloy steel showing a hardness of 62 which had an elastic limit of 230,000 lbs. per sq. in. I readily believe that the testing machine may show this reading, but I do not regard such machines as capable of defining the elastic limit closely enough. As an example, I have secured heat-treated specimens of the higher nickel steels which were said to possess a high elastic limit by the tensile testing machine; but the bending or compound-stress machine showed that while the elastic limit was taken at a load where rapid yield without further load begins, a considerable permanent set took place under but a fraction of the load referred to, so that machinery parts made of that material would easily be disaligned.

Such steel does not exhibit the same curve that nearly all other steels do. Like copper, it stiffens more and more under permanent set, so that granting that a little permanent set is allowable, it would increase in strength with increase of load up to the final rapid yield seen beyond all elastic limits. I should like to know if others have found this condition, which I regard as too delicate for detection by the single-stress machine. To my mind such steel has no definite elastic limit.

I wish to point out that in comparing carbon steel with alloy steels, all must be hardened clear through or to exactly the same depth. Carbon steel will thus usually show low elastic-limit readings, because it does not harden to as great a depth in the test piece as do alloy steels.

It is quite generally agreed that exact relations between hard-

Mr. Shore. ness and elastic limit can be obtained only on materials of like composition. Otherwise, the results would be approximate, unless some allowances are made affecting lack of toughness and the modulus of elasticity.

Mr. Stoughton. MR. BRADLEY STOUGHTON.—The industrial importance to-day of testing iron, steel and other metals for hardness can readily be seen by observing the extent to which it is used in factories. It seems as if there were hardly a progressive plant where metals are used or treated, that does not operate some form of this test. Many employ it constantly, and have already established upon such a basis self-imposed standards and specifications for controlling operations or for treating metals, especially hardening steel and like processes. No doubt the next step will be the interchange of materials according to specifications in which a test for hardness will appear, and this will be an advantage to both manufacturer and consumer in many cases, provided the test is applied, and the specifications are drawn, intelligently.

Possible Failures of Hardness Tests.—Probably we could all cite instances where hardness tests have been applied with the hope of obtaining light upon some dim details of practice, and then abandoned as worthless for the purpose in mind, after more or less patient experimenting. Some of these failures are the fault rather of the method of application than of the test itself. No one form of test is suitable for every condition and experience, and other forms, though eminently suited, require more intelligent operation than has been given them. The quality known as hardness has never been satisfactorily defined; there is, (1) cutting hardness, such as that desired in machine tools; (2) abrasion or wearing hardness, such as that desired in railroad rails, gear teeth, jaws of crushing machines, etc.; (3) resistance to penetration, such as that desired in armor plate; (4) resiliency or elasticity, such as that desired in springs; and (5) brittleness. Each of these qualities seems to be a separate manifestation of the generic property which we know as hardness. An instrument that would measure one of them might give a false indication of some of the others. For example, an instrument very successfully used for testing tempered steel tools, gives a higher value for the "hardness" of india rubber than for that of cast iron. Again, the outside layer of Krupp armor plate and manganese steel are both well

adapted to resist the penetration of a projectile, but the former is brittle and the latter is tough; the former has a relatively high elastic limit and the latter a low one; neither is well suited to cutting-tool work; manganese steel can easily be scratched with a needle and the other can not; yet manganese steel resists wear better than Krupp armor. **Mr. Stoughton.**

The more nearly fool-proof an instrument is, and also the more nearly automatic in communicating the results of a test, the better; but if it is not capable of measuring the specific form of hardness desired, of what service is it, though it be both fool-proof and automatic, or nearly so? In such a case it seems to me better to go without the test, or else to get a suitable machine and a trained man to operate it, if constant operation is required.

Forms of Hardness Tests.—There are at present several forms of hardness tests, from the ordinary file backed by experience to the large machine recently designed to test the wearing qualities of railroad rails. Resistance to penetration was long tested by the United States Ordnance Department by means of a weighted punch, and a somewhat similar result was obtained by means of a series of needles of graded hardness which were tried in succession until one was found that would scratch the material under test. But a more exact method is the sclerometer of Turner. This method makes use of a diamond point which is drawn across the surface to be measured and then back again. The weight required upon this point to make a barely visible scratch determines the degree of hardness.* All these methods, like the Shore scleroscope, determine only the hardness of the surface of the specimen. On the other hand, the Keep test drills deep into the specimen and gives a measure of the work required to cut out the metal, thus testing not only the surface, but also the interior. The Jaggar instrument is similar, but uses a small diamond drill in connection with a microscope. In the Brinell test, a hardened steel ball is forced into the specimen with a standard pressure or pressures; the measurement of the indentation made determines the degree of hardness. The pressure may be either static or dynamic, and more scientific work has been done upon this form of

* Instead of applying the instrument in this way, we prefer to use a series of standard weights and then measure under a microscope the width of a scratch made by one of these.

Mr. Stoughton. hardness test than upon any other. A relation has been established between the results obtained thereby and the ultimate tensile strength and elastic limit of different grades of material. In the *Revue de Métallurgie* and the *Proceedings of the International Association for Testing Materials* will be found some very interesting researches dealing with the results of the Brinell test.

Professor Turner investigated the relation between the degree of hardness shown by the static Brinell test, the Keep drill, the Shore scleroscope, and his own sclerometer, and published the results in the *Journal of the Iron and Steel Institute*, 1909. This research showed that, with pure metals, there was a comparatively close agreement between the results with the different instruments, but with treated metals, with some alloys, and, most of all, with tempered steels, there were great discrepancies; so that it was evident that each method of test measured a different form of hardness in the tempered and alloy states.

Hardness of Cutting Tools.—When the Shore test can be satisfactorily applied, it is the easiest and quickest to operate and requires the least skill. It is very useful for testing cold-rolled material and tempered cutting tools at different points on the cutting edge. Many machine shops to-day apply some form of hardness test to every new material that comes to them, either for making tools or to be cut. From the results of these tests, on the basis of past experience, they can determine the best heat for tempering and best shape of tool to get the quickest and most economical work. The Shore test has a further advantage in this respect in that it does not injure the material.

Segregated Metal.—It is said that the Shore test is also useful for testing for segregation, but the test is evidently only a superficial one, and might readily lead to misplaced confidence. In case the material to be tested is in thin pieces, special precautions must be taken with the Shore test, as the thickness of specimen and the character of support will otherwise cause a variation in the results obtained. With the Jaggar instrument this is not so, but this test results in injury to the material tested.

Case-Hardened Steel, Etc.—In the matter of case-hardened steel, all instruments which test the surface only are liable to give misleading indications. Many automobile manufacturers case-harden their gears not more than $\frac{1}{64}$ in. deep, and the short-

lived character of this skin would not be discovered by the Turner, the Shore, or the graded needle* tests. Under such circumstances the Brinell or Jaggar tests would show the hardness to an appreciable depth, although this result would not necessarily correspond with the wearing quality of the gear, except in a general way. A somewhat similar case is that of hardened pieces which are subjected to pressure and shock, as, for example, dies for drop-forging, etc. Here, not only the skin hardness is important, but also the rate at which the hardness falls off below the surface. If the metal is too soft underneath, the skin will drop and form a surface crack which ruins the die for further service. In more than one case, instruments which test only surface hardness have been known to fail under such conditions, and to have been abandoned. The Brinell test would seem to be well adapted for such cases, if it could be applied without ruining the dies. The same may be said with regard to testing projectiles, where surface-hardness tests are liable to be misleading. **Mr. Stoughton.**

Bearing Metals.—There is a class of bearing metals which depends on the formation of metallic compounds within the alloys. These crystals should be very hard and imbedded in a soft matrix. The hard crystals support the rotating weight and the soft matrix serves as a lubricant. The Jaggar "microsclerometer" would seem to be especially adapted to apply in specifications for bearing alloys of this class, because, by means of the attached microscope, one should be able to test the hardness of the different constituents. It would also seem to be possible for the makers of the Shore instrument to connect a microscope to it, so that it could be used in the same manner.

Machining Qualities of Iron Castings.—The Keep drill is used so largely for determining the machining qualities of iron castings, and is so well adapted for the purpose, that it seems unnecessary to do more than refer to the test here.

Wearing Qualities of Rails, Etc.—It is said that rails are tested for wearing qualities with some success in Germany by means of the Brinell test, but they have not yet been long enough in actual service to prove the reliability of the results. It is well known that a large machine to test this quality in rails under

* This graded needle test is sometimes described as a modification of the Mohs' mineralogical scale.

Mr. Stoughton. conditions resembling those of service has recently been designed, and we shall no doubt have some practical results therefrom in the near future.

Resiliency of Springs.—From information in my possession, it would appear that the Shore test could be applied to determine the resiliency of springs, and to apply in specifications and control their heat treatment, without injuring the springs themselves. There is a large loss annually due to premature failure of springs, especially in railroad service, and a test is needed which could be applied to every spring after it is ready for use.

This and other problems upon which tests for hardness will apply, offer an opportunity to render material benefit to the industries in which we are all interested. The International Association for Testing Materials has published much valuable information, but of a scientific rather than an industrial nature. It would seem as if our American Society might well take up the work of bringing the available information to a point where it may be useful to many.

Mr. Shore. MR. SHORE (*by letter*).—I do not regard it as proper to compare the rebound of the scleroscope drop hammer on rubber with the rebound on cast iron or any other metal, because rubber is not a perfect solid in the same sense as a metal. It is very resilient compared to a metal. Here some discretion must be used and allowances made for the peculiar properties of different materials. Let me cite an example: The scleroscope tests wood very nicely, but since wood is about six times as resilient as a metal, the reading should be divided by six under this form of test. The method used to compare the hardness of wood with that of a metal is that advocated by Foppl, which I described in my paper—namely, to nick the corners of each substance together. Similarly, the scleroscope is used the world over for testing carbon, but no attempt has been made to compare its hardness with that of metals, if the readings are the same. Its proper application has thus rendered it indispensable.

With regard to testing the depth of hardening, I should say that there is at present no instrument which can be used in ordinary shop practice. The Brinell machine is serviceable in case-hardened work provided the hardened case is not too deep. One-eighth inch would perhaps be considered the limit. The hardness of the inte-

rior must be a constant factor; and when it varies, as it usually does, the ball test will also give misleading results. Mr. Shore.

In some dies and also in armor plate and projectiles, the depth of hardening is often over 1 in., and can only be obtained by using the proper steel alloy. For these great depths of hardness there is nothing we know of that can adequately meet the situation. Directly applied, the scleroscope naturally measures the hardness of the surface. Indirectly applied, any result that is of value in connection with the depth of hardening can be obtained. In ordinary case-hardening where the depth is less than $\frac{1}{16}$ in., it is the practice to grind a small nick on some unimportant part of the specimen, so that the scleroscope can be applied to the exposed surface.

In this manner we may obtain the hardness of the surface, as well as the depth of hardness and the hardness of the core, which is of vital importance. While we cannot determine the depth of hardening of armor plate and the like when properly hardened, we can, by the use of the scleroscope and a test sample of fair size, tell beforehand whether or not under a favorable heat treatment the large piece will harden deep enough.

APPARATUS FOR THE MICROSCOPICAL EXAMINATION OF METALS.

By Albert Sauveur.

When the distinguished English microscopist, Sorby, first applied the microscope in 1864 to the examination of the structure of meteorites, and later, of iron and steel samples, he used for his now famous pioneer work an ordinary microscope, a Beck vertical illuminator, and a simple source of light. That he was able, with such inadequate outfit, to obtain the remarkable results published by him, testified of the patience and exceptional skill of the operator. Since Sorby's time the instruments needed for the microscopical study of metals have been greatly improved, and, in view of the constantly increasing importance of metallography, a short description of the appliances I have found most satisfactory after an experience of nearly twenty years, may not be without interest to the members of this Society.

Many forms of microscope, many sources of light, and many special devices are now offered to metallographists for which manufacturers claim a superiority often exaggerated and sometimes altogether unwarranted. It is hoped that this brief consideration of the subject will be of real assistance to those interested in the selection of metallographic apparatus.

The Microscope.

While any good microscope of the ordinary type, substantially built and provided with a satisfactory fine adjustment, may be used with a certain degree of success for the examination of metals and alloys, those who are restricted to its use will soon find themselves seriously handicapped in several directions and unable to obtain the desired results. The following considerations will make this clear.

The Stage.—Ordinary microscope stands being constructed for the examination of objects by transmitted light, i. e., by light

proceeding from below the stage and passing through the object on its way to the eye, are provided with fixed stages. This, however, is a serious objection when the instrument is applied to the examination of metals and other opaque objects which must necessarily be illuminated by light directed upon them from *above* the stage, and which therefore require the use of an "illuminator" attached to the objective and consequently moving with it. It will be readily understood that it is of considerable importance that the position of this illuminator, and therefore of the objective to which it is attached, be kept constant, once the necessary adjustments are effected, since any change in its position would require a re-adjustment of the source of light, the condensing lenses, diaphragm, etc. To that effect the stage should be provided with a rack and pinion motion by means of which the coarse focusing at least may be done (Fig. 1).

This rack and pinion motion of the stage, moreover, results in a much greater working distance, allowing plenty of room for the insertion of the illuminator and nose-piece, the use of specimen holders, and the examination of bulky specimens with low-power objectives. In the microscope illustrated in Fig. 1, the working distance measures over 5 ins. as against 4 ins. or less in ordinary stands.

I suggested this rack and pinion mounting of the stage to the Bausch and Lomb Optical Company of Rochester, N. Y., in 1897. It was soon adopted by other manufacturers and is now considered an indispensable feature of all metallurgical microscopes.*

By not departing more than necessary from the usual construction of microscopes, none of the essential features required for the examination of transparent preparations need be sacrificed, and the full efficiency of the microscope is retained for such examination, sub-stage condensers, polarizing prisms, etc., being

* In order to render this vertical motion of the stage unnecessary and thus be able to apply ordinary microscopes to successful metallographic work, it has been suggested to attach the source of light to the vertical illuminator, the light moving with the microscope tube. The clumsiness of such a scheme will be apparent as well as the objection of having a very hot source of light placed in such close proximity of the microscope and microscopist. It should be borne in mind, moreover, that a vertically movable stage is necessary also because of the much greater working distance which it affords. Without its use, it is impossible to examine bulky specimens with low-power objectives.

readily attached when needed. The possibility of applying his instrument to all kinds of microscopical work with equally satisfactory results should appeal strongly to the metallographist, for there is no laboratory where, occasionally at least, examination of transparent objects is not desirable or even imperative.

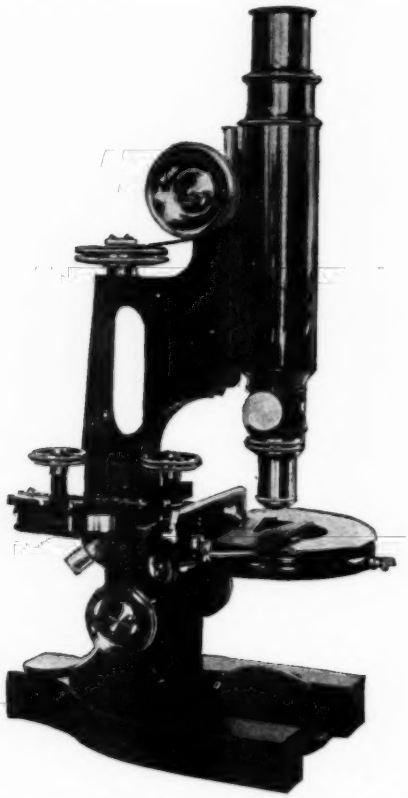


FIG. 1.—Metallurgical Microscope, Eye-Piece, Vertical Illuminator, Objective, Magnetic Specimen Holder, and Mechanical Stage.

The microscope illustrated in Fig. 1 is almost universally used in this country for metallographic work.

(*a*) *Plain Stages.*—While a mechanical stage adds greatly to the convenience of the manipulations, a plain stage may be used with satisfactory results. It should be provided with strong clips to

hold in place the specimen holders soon to be described, and should preferably be circular and revolving (Fig. 2). When provided with centering screws like the stage of the stand illustrated in Fig. 1, the object may be moved gently while under examination, a very desirable feature especially when using high-power objectives, in which case the moving of the object entirely by hand is very jerky. In order to derive the full benefit of the use of the magnetic holder described later, the central opening of the stage should not be less than $1\frac{1}{4}$ ins. in diameter.

(*b*) *Mechanical Stages.*—The great superiority of a mechanical stage permitting, as it does, a systematic examination of the object

FIG. 2.—Plain Stage, Revolving and Provided with Centering Screws, and Magnetic Specimen Holder.

over its entire surface, need not be insisted upon. In connection with the magnetic holder it makes it possible, moreover, to examine repeatedly and at any time the same spot of any specimen, as will soon be explained. The mechanical stage illustrated in Fig. 3 has been especially designed to fit my metallurgical microscope (Fig. 1), and is very readily substituted for the plain stage. The central opening measures $1\frac{5}{8}$ ins. in diameter, permitting the convenient use of the magnetic holder.

Objectives.—Ordinary achromatic objectives give satisfactory results. They should, however, be corrected for uncovered objects, as the placing of cover glasses over bright metallic surfaces is

accompanied by light reflection causing loss of clearness and definition.

It is also highly desirable that the objectives be provided with short mounts so as to bring the reflector of the vertical illuminator as near the back lens of the objective as possible, as this will materially decrease the amount of glare caused by the reflection of light by the lenses of the objectives. Three objectives, one of low,

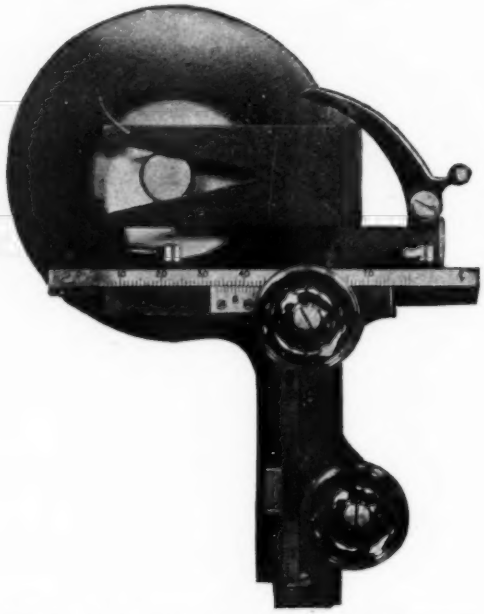


FIG. 3.—Mechanical Stage to Fit Metallurgical Microscope, and Magnetic Specimen Holder.

one of medium, and one of high power, will generally suffice for metallographic work. The following focal lengths are recommended: 32-mm. or $1\frac{1}{3}$-in., 16-mm. or $\frac{2}{3}$-in., and 4-mm. or $\frac{1}{6}$-in. In case a higher power is needed, the 2-mm. or $\frac{1}{12}$-in. oil immersion objective will be found very satisfactory. When a very low power lens is required, as for instance in the examination of fractures or of very coarse structures, a 48-mm. or 2-in. objective will give good results. I suggest that it be provided at its lower end with a society screw to permit the attachment of the vertical illuminator which, in

the case of such low power lenses, should be placed between the object and the objective, as explained later.

While apochromatic objectives are, of course, superior to achromatic lenses, their cost is very much greater, and fortunately their use is not by any means indispensable, excellent results being obtained with achromatic objectives.

In case it is imperative to secure high-power photomicrographs of maximum clearness and definition, the Zeiss 4-mm. (0.95 numerical aperture) dry apochromatic objective and the Zeiss 2-mm. (1.40 numerical aperture) homogeneous immersion apochromatic objective are recommended, used in connection with compensating eye-pieces Nos. 4 and 8, when they will yield magnifications varying between 250 and 1000 diameters.

Eye-pieces.—With achromatic objectives ordinary Huygenian eye-pieces are used. Two eye-pieces, respectively of 1-in. and 2-in. focal length, will generally cover the range of magnification needed.

For the taking of photomicrographs, projection eye-pieces possess some superiority, especially when high-power objectives are used, as they then yield flatter and more sharply defined images. The Zeiss projection eye-piece No. 2 is very satisfactory.

Nose-pieces.—The use of nose-pieces makes, of course, for convenience in manipulation, as it permits the rapid change of objectives. They are not recommended, however, for metallographic work owing to the fact that by increasing the distance between the back lens of the objective and the illuminator they increase the glare, as already explained.

Iris Diaphragms.—Iris diaphragms are sometimes inserted between the objectives and the illuminator so as to control the size of the pencil of light proceeding from the object, with a view of securing sharper definition. Their use in that position, however, is of doubtful value, as it may cause some distortion of the image. It seems preferable to place the iris diaphragm between the source of light and the illuminator, thus regulating the amount of light *entering* the latter. When placed between the objective and the illuminator it increases, moreover, their distance apart, which we have seen to be objectionable. If a diaphragm must be attached to the microscope, it is better to place it between the tube nose and the illuminator. When using low-power lenses it might also be

screwed to the lower end of the objective, thus controlling the light returned by the object *before* entering the objective.

Specimen Holders.—In order to examine a piece of metal under the microscope, it is of course necessary that the polished and otherwise prepared surface be held in a plane accurately perpendicular to the optical axis of the instrument. This may be accomplished by so shaping the sample that it will have two sides

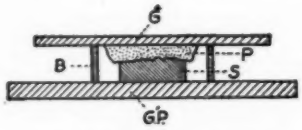


FIG. 4.—Stead's Method of Mounting Samples of Metals for Microscopical Examination.

exactly parallel, and preparing one of them for microscopical examination. This operation, however, is at best tedious and laborious, and metallographists have endeavored to replace it by the use of more or less ingenious devices for holding the specimens in the proper position. Some embed their samples in wax or in some other plastic material, while others have recourse to stages provided with special levelling devices. These schemes have been fully

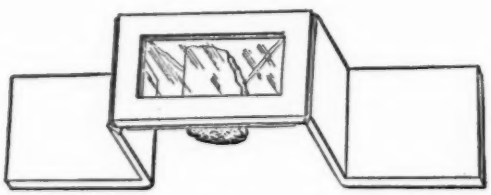


FIG. 5.—Specimen Holder.

described and it is unnecessary to recall here their unsatisfactory character. Mr. Stead's method of embedding his samples is so clearly shown in Fig. 4 that it does not require further description. It calls for a supply of brass rings of different sizes with edges accurately parallel.

The simple holder (Fig. 5) which I designed in 1892 gave much greater satisfaction, requiring no mounting whatever of the samples. The specimen, no matter how irregular in shape, is

held firmly in place by a rubber band and the holder placed on the stage like an ordinary slide. If the correction of the objective demands it, a cover glass may be inserted between the sample and the holder. It will be apparent that the required manipulations are very simple and quickly performed. This little holder is, I think, very widely used in this country.

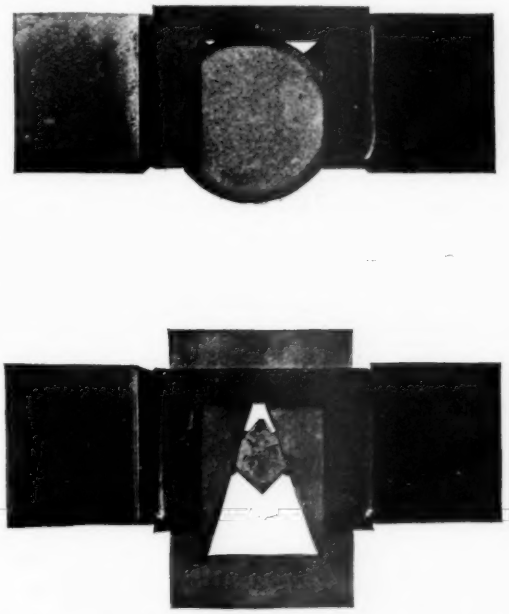
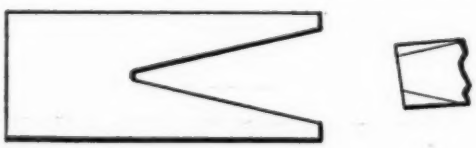


FIG. 6.—*a*. Specimen Holder and Large Sample.
b. Specimen Holder, Templet, and Small Sample.

In the case of specimens smaller than the opening of the holder, however, the use of a cover glass is necessary to hold them in place. This is objectionable, at least when using high-power objectives, which should be corrected for uncovered objects To overcome this difficulty, I suggest the use of a little templet having a triangular opening and inserted between the specimen and the holder (Fig. 6). This templet is made very thin so as to permit the use of high-power objectives, which must be brought very close indeed to the object. It will also be noticed that one side of the

upper part of the holder has been removed, exposing to view a larger portion of the sample and permitting a more ready approach of high-power objectives. Large samples are, of course, placed in the holder without any templet.

It occurred to me recently that a still simpler and more effective device could be used to hold in place samples of iron and steel and other magnetic substances. The results obtained were highly satisfactory and I am confident that the value of this little holder will be fully appreciated by those who apply the microscope to the examination of iron and steel samples. The device consists of a V-shaped permanent magnet of special steel, about 1 in. wide and $2\frac{1}{2}$ ins. long (Fig. 7). This little magnet is placed on the stage of the microscope like an ordinary glass slide (Figs. 2 and 3) and the sample to be examined suspended to it from below, being



a *b*

FIG. 7.—*a*. Magnetic Specimen Holder.
b. Scratched Specimen.

held in place by the attraction of both poles. Small samples are suspended near the small end of the V-shaped opening, while larger ones are placed nearer the wider end of the opening. This holder, therefore, is universal in its application within the limits of samples of suitable size for microscopical examination. Two and even three samples may be suspended to the magnet and examined in quick succession, greatly facilitating the comparison of their structure. If the opening of the stage be sufficiently large, say $1\frac{1}{4}$ ins. or more in diameter, the magnet may be kept permanently on the stage, as the samples may then be readily removed or attached to the magnet with the fingers from below the stage. This adds so much to the convenience of this little device that it is strongly urged, in case the central aperture of the stage is too small, to have it suitably enlarged. The magnet is kept in place, like any glass slide, by the clips of the microscope and, also like any glass slide, may be moved about for the inspection of the different parts of the speci-

men. The side of the magnet resting on the stage having been ground perfectly flat, it will be evident that the surface of the sample under examination will always be accurately in the proper position, permitting the use of high-power objectives without fear of difficulty arising from ever so slight an inclination of the sample.

When used in connection with a mechanical stage (Fig. 3) the convenience of this little holder becomes still more apparent and its usefulness is further increased. It then affords, moreover, a ready means for the repeated examination of the same spot of any sample at any time. To that effect the holder is laid upon the prepared surface and two scratches made by drawing a needle across the specimen along the sides of the V-shaped opening, as shown in Fig. 7. When it is desired to examine the sample, the latter is suspended to the magnet so that the needle markings coincide closely with the sides of the magnet opening, in this way securing a permanent position for the sample. The position of the magnet itself is controlled, in the usual way, by means of the graduating devices of the mechanical stage.

Finally, by placing the sample below the stage and bringing the prepared surface on a level with the stage, considerably greater working distance is secured, a gain which has its importance.

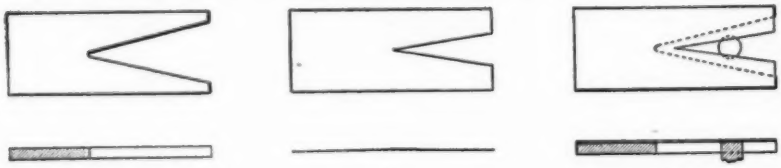
The only limitation of this holder is due to the fact that with very small specimens it is impossible to use high-power objectives ($\frac{1}{6}$ in. or less in focal length) because the mounting of the objective comes in contact with the sides of the magnet and prevents the focusing of the object. For the examination by high-power objectives, I recommend the use of a very thin steel templet (not over 0.01 in. thick) of the same dimensions as the magnetic holder, but with a V-shaped opening considerably narrower (Fig. 8). This templet is placed over the magnetic holder so as to exactly cover it, thereby becoming magnetized. The small iron and steel samples are suspended to this thin steel plate in the usual way and may then be examined with the highest power objectives.

ILLUMINATION OF THE SAMPLES.

Opaque objects such as metals and alloys must necessarily be examined by reflected light, i. e., by light thrown upon them from above the stage, their treatment differing in this from that of other microscopic preparations, which are generally examined by trans-

mitted light, i. e., by light sent through them and proceeding from below the stage.

With low-power objectives there are two possible ways of illuminating opaque specimens; (1) by directing the light obliquely upon the object, and (2) by causing the light to fall perpendicularly upon it by means of so-called "vertical illuminators." With medium-high and high-power objectives only the second method is possible, because the distance between the specimen and the front lens of the objective is now so small that obliquely reflected light cannot reach the surface under examination. With very low power objectives—i. e., having a focal length of 1 in. or more—the vertical illuminator may be placed between the lens and the object; but with higher power objectives, it must of course be inserted



(*a*) (*b*) (*c*)

FIG. 8.—*a*. Magnetic Holder.
b. Steel Templet.
c. Magnetic Holder, Templet, and Sample.

between the objective and the microscope tube, the objective then acting as a light condenser and increasing the intensity of the illumination.

Oblique illumination may be obtained (*a*) by allowing daylight or artificial light to fall freely upon the object; (*b*) by directing the light upon the object by means of mirrors, reflectors, or condensers; (*c*) by the use of a "lieberkühn;" and (*d*) by the use of a "parabolic reflector."

Vertical illumination may be produced (*a*) by means of an opaque reflector consisting of a totally reflecting prism or of a mirror covering only a portion of the objective, the light returned by the object reaching the eye by passing through the uncovered portion; and (*b*) by means of a transparent reflector, generally a plain glass disc or glass square, reflecting upon the object a portion of the incident light and permitting the passage of a portion of the light returned by the object, which thus reaches the eye.

When a highly polished surface is examined by obliquely reflected light, since the angle of reflection is equal to the angle of incidence, the totality of the light is reflected outside the objective (Fig. 9) and the object appears uniformly dark. In case the metallic specimen contains some portions duller in appearance, these will scatter a certain amount of light a part of which will enter the objective (Fig. 9), and those portions will therefore appear brighter. A similar effect is produced when the specimen instead of being perfectly flat contains microscopic hills and valleys, the sides of which may be so inclined as to reflect some light into the micro-

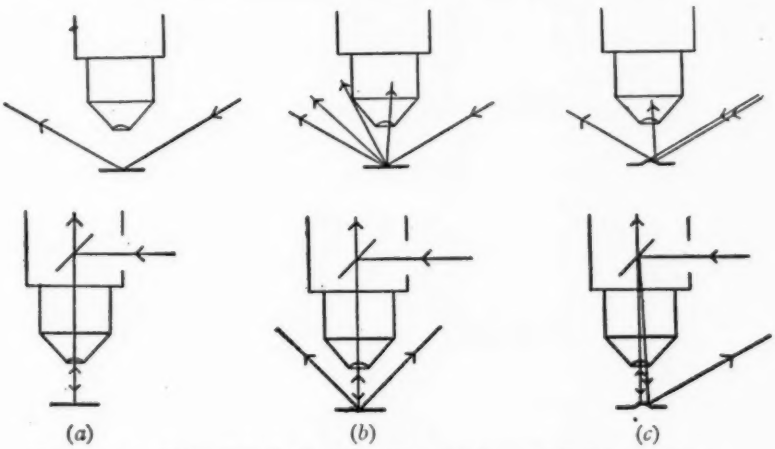
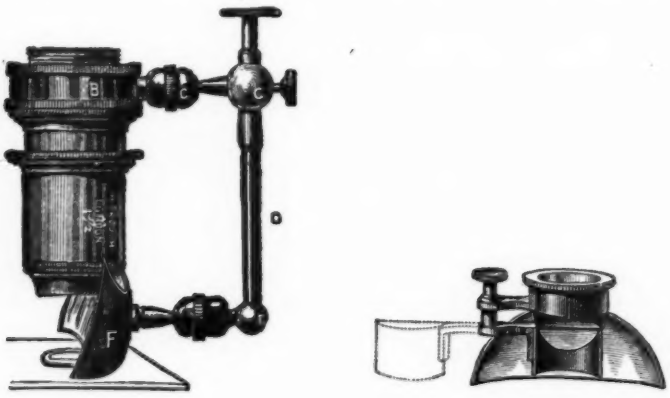


FIG. 9.—*a*. Oblique and Vertical Illuminations of Bright Surface.
b. " " " " " Dull "
c. " " " " " Hills and Valleys.

scope (Fig. 9), consequently appearing bright. Viewed by oblique light, therefore, the relative darkness or brightness of a constituent will vary inversely with its true appearance and will also depend upon its orientation, since this will affect the angle of incidence of the light striking it. Generally speaking, the darker a constituent the brighter will it seem to be when illuminated by oblique light, the latter yielding, so to speak, a negative image. Oblique illumination, moreover, cannot be made as intense as vertical illumination, and, as already explained, is possible only with low-power objectives. For these and other reasons, while it is not without value, it is only used occasionally by metallographists.

To increase the intensity of oblique illumination and to make its use possible with somewhat higher powers, such appliances as the "lieberkühn" and the parabolic reflector have been used. The "lieberkühn," so called from the name of its inventor, consists of a small concave mirror attached to the objective and reflecting upon the object some light proceeding from below the stage and passing around the object. It will be evident that only small-size objects can be thus illuminated.

The parabolic reflector (Fig. 10), first constructed by Messrs. Beck of London for Dr. Sorby, consists of a parabolic mirror placed



(*a*) (*b*)

FIG. 10.—*a*. Parabolic Reflector.
b. Sorby-Beck Parabolic Reflector.

on one side between the objective and the object and condensing the incident light upon the latter. It should be attached to the objective. Dr. Sorby later added a silver mirror in the shape of a half disc to the same mount, so as to be able to obtain at will vertical and oblique illumination when using low-power objectives (Fig. 10). When vertical illumination is desired, the small mirror is swung over the objec ive, covering only a portion of it, and directing vertical rays of light upon the object. This combination is known as the Sorby-Beck reflector.

The effects of a vertical illumination are precisely opposite to those of an oblique illumination, as clearly shown in Fig. 9, highly polished surfaces reflecting the totality of the light into the

objective, while dull ones appear dull because they reflect most of the light outside.

To produce a ver ical illumina ion we have the choice between an opaque or a transparent (glass, generally) reflector. The opaque reflector consists of a totally reflecting right-ang'ed prism, or of a mirror placed between the microscope tube and the objective and covering only a portion (generally abou one-half) of its aperture. The beam of light enters the illuminator through a side opening provided for that purpose and is reflected downwards by the reflector, being condensed upon the object by the lenses of the

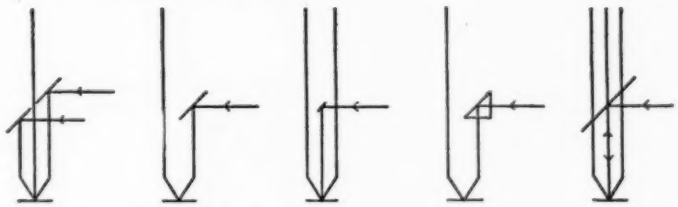


FIG. 11.—*a*. Annular Mirror.
b. Semi-Circular Mirror.
c. Central Mirror.
d. Totally Reflecting Prism.
e. Plain Glass Disc.

objective itself. The light sent back by the object reaches the eye through the uncovered part of the objective.

The first vertical illuminator was designed by Professor Hamilton L. Smith of Hobart College, Geneva, N. Y., and consisted of a small annular silver mirror (Fig. 11), forming an angle of 45° with the axis of the microscope, the light reflected by the object passing through the central opening on its way to the eye. Semi-circular mirrors, similarly mounted and partially covering the objective (Fig. 11), have been used with equal satisfaction, and I have obtained good results with a very small central mirror (Fig. 11) suitably mounted, reflecting the light upon the central portion of the objective lenses, and permitting the returned light to reach the eye through the free space surrounding the mirror.

Instead of a mirror, a totally reflecting right-angled prism may be used as shown in Figs. 11 and 12, covering half of the aperture of the objective. The prism is so mounted that it can be

rotated around its horizontal axis, this being needed in order to secure the best illumination of the sample. Nachet, of Paris, provides his prism with an additional motion permitting it to cover a greater or smaller portion of the objective. These reflecting prisms are now used much more than the reflecting mirrors.

A modification of the prism illuminator is shown in Fig. 13, as a part of an inverted microscope resembling the Le Chatelier type to be described later. Two right-angled prisms are cemented together the upper one being silvered over an elliptical area, thus intercepting the light proceeding from the object S and reflecting

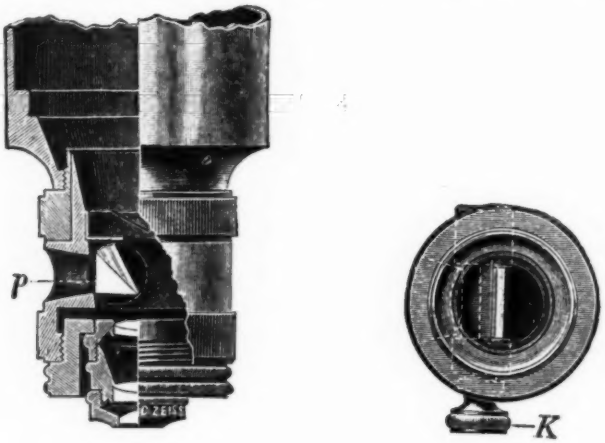


FIG. 12.—Vertical Illuminator. Zeiss Totally Reflecting Prism.

it at right angles into the microscope tube O and hence to the eye, while the incident light from M passes freely through the unsilvered part of the prisms, being condensed upon the object by the objective in the usual way. It will be evident that this arrangement is very similar in its working to the small central mirror already mentioned (Fig. 11).

In 1874, Nachet constructed for the International Commission of the Meter some objectives provided with totally reflecting prisms as permanent parts of their mountings. In low-power objectives a prism was placed above the first lens (Fig. 14), while with higher power objectives it was necessarily inserted above the double or triple lens system. These objectives are called illuminating

objectives. This arrangement, however, has not been found very satisfactory and with one notable exception is seldom used by metallographists.

In vertical illuminators having a transparent reflector, the

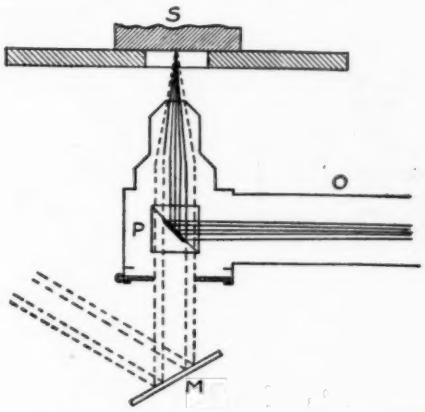


FIG. 13.—Vertical Illuminator. Double Prism.

latter consists of a plain glass disc covering the whole of the aperture of the objective (Figs. 11 and 15). The incident light is in part reflected upon the object, while another portion passes freely

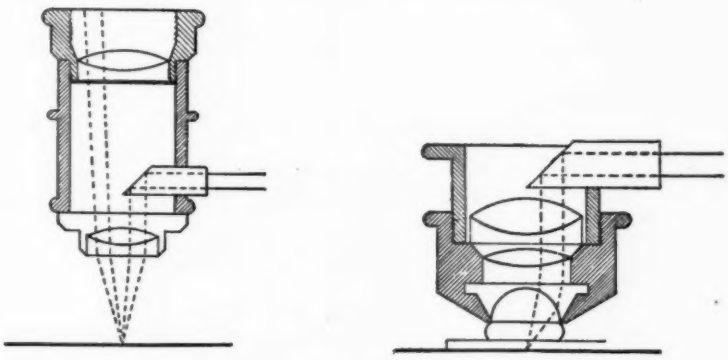


FIG. 14.—Nachet Illuminating Objective.

through the glass reflector. A part of the light returned by the object is again reflected by the glass illuminator, while another portion passes through it and thus reaches the eye. The

glass reflector is so mounted that it can be rotated around its horizontal axis (Fig. 15). The amount of light permitted to enter the illuminator may be regulated by an iris diaphragm attached to the side opening or independently mounted and placed between it and the source of light, or by a revolving sleeve attached to the

FIG. 15.—Bausch and Lomb Plain Glass Disc Vertical Illuminator.

illuminator and provided with different size openings. The first plain glass illuminator was constructed by Mr. Beck of London.

With very low power objectives it is preferable to place the vertical illuminator between the objective and the object, attaching it to the former in some suitable way, as for instance according

FIG. 16.—Stead's Device for Placing Vertical Illuminator between Objective and Object.

to Stead's device, shown in Fig. 16, consisting of a cover glass mounted in a brass tube which slips over the lower part of the objective. As a possibly simpler arrangement, I suggest providing the lower end of the objective with a society screw so that the vertical illuminator may readily be inserted at will above or below the objective.

I am well aware that some metallographists of note prefer

the prism to the plain glass type of vertical illuminator. In my opinion, however, the plain glass reflector is greatly superior. While the illumination obtained by its use is not quite as intense, it is certainly more uniform and less liable to produce a distortion of the image.

An improved construction of the plain glass vertical illuminator is illustrated in Fig. 15. The glass reflector is inserted into a brass ring which on the side opposite the milled head is screwed into the wall of the brass mounting, practically doing away with

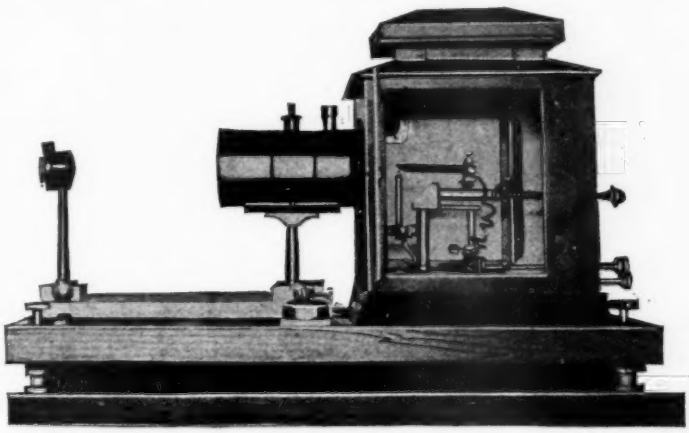


FIG. 17.—Large Electric Arc Lamp, Condensing Lenses, Cooling Cell, Iris Diaphragm, and Optical Bench.

the frequent breaking of the glass and greatly facilitating its cleaning. The milled head is large, which makes it possible to impart a more delicate motion to the glass reflector.

SOURCES OF LIGHT AND CONDENSERS.

The illumination of opaque objects such as metals and alloys requires an intense source of light, especially for their photography. Daylight and ordinary gas or oil flames should be discarded as not suitable for the purpose, and one of the many different kinds of artificial lights selected. Electric arc lamps, Nernst lamps, electric incandescent lamps, acetylene lamps, oxy-hydrogen lamps, and Welsbach lamps, should be considered. These are illustrated in Figs. 17 to 23, inclusive.

Two kinds of electric arc lamps are now supplied, one with large carbons (Fig. 17) and a smaller one with carbons measuring only ¼ in. in diameter (Fig. 18). The carbons should be placed at right angles, as this arrangement directs the maximum amount of light into the condensers. The positive or horizontal carbon should be cored and larger than the vertical or negative carbon. While automatic feeding of the carbons is a valuable feature, it is not by any means essential, as remarkably effective hand-feed lamps are now constructed by which a very steady light can be maintained (Fig. 17*a*). Automatic mechanisms, moreover, are

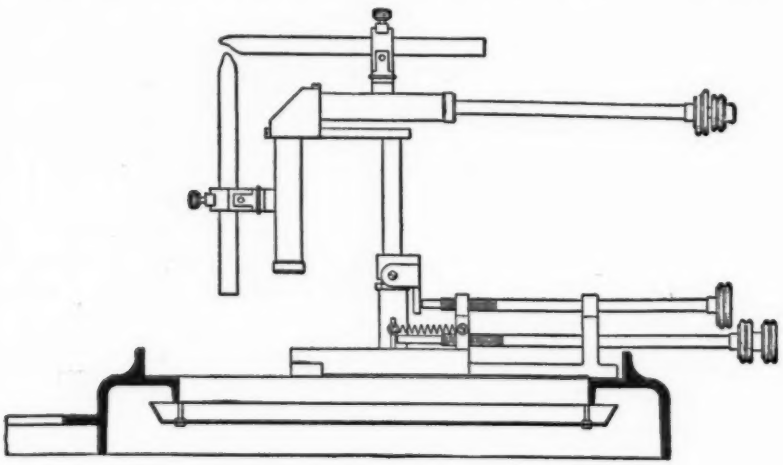


FIG. 17*a*.—Large Arc Lamp—Adjusting Mechanisms.

liable to get out of order and occasional sudden shiftings of the light are difficult to entirely eliminate.

The large carbon lamp yields of course by far the most intense illumination and is the only one suitable for direct projection of metallic samples upon a screen for public exhibition. In taking photomicrographs with the large arc lamp the needed exposures are often instantaneous and seldom exceed five or, at the most, ten seconds. The lamp consumes from fifteen to twenty amperes.

The small arc lamp (Fig. 18) is very satisfactory for visual examination and is, of course, much less expensive. It, however, requires much longer exposures when photographing. The position of the carbons can be regulated with great nicety by inde-

pendent adjustments, thus securing a very uniform light. The lamp consumes about five amperes.

The Nernst lamp (Fig. 19) is used successfully by many

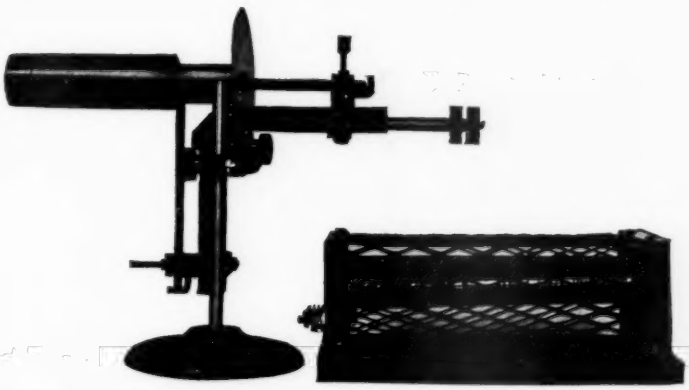


FIG. 18.—Small Electric Arc Lamp, Bull's Eye Condenser, and Rheostat.

microscopists and undoubtedly affords a very satisfactory illumination both for visual examination and for photomicrography. In taking photographs, exposures of ten seconds or more are

FIG. 19.—Nernst Lamp.

needed, according to the magnification and the character of the specimen.

The incandescent electric lamp (Fig. 20) is not so satisfactory and is lacking in intensity for photographic work. One-hundred-candle power bulbs should be used.

The supply of acetylene gas in tanks by dealers in automobile supplies has made the use of acetylene lamps (Fig. 21) much more

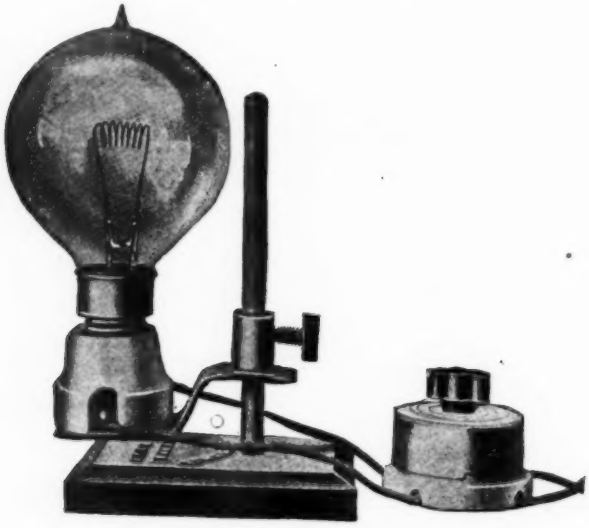


FIG. 20.—One-hundred-Candle-Power Incandescent Electric Lamp.

convenient than formerly for microscopical work. It gives a very satisfactory illumination for visual work but is lacking some-

FIG. 21.—Acetylene Lamp and Reflector.

what in intensity for photographing, especially with high-power objectives.

The oxy-hydrogen lamp (Fig. 22), while giving a somewhat

more intense illumination than the acetylene lamp, is not so convenient and is hardly to be recommended for metallographic work.

In the Welsbach lamp (Fig. 23) we have a cheap, steady,

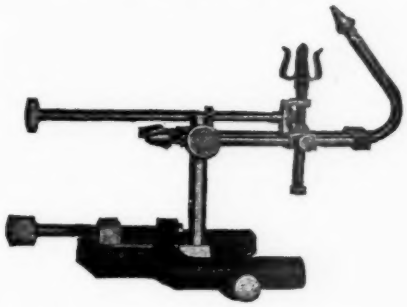


FIG. 22.—Oxy-hydrogen Lamp.

convenient and satisfactory source of light for visual examination, at least with low and medium high-power objectives. It is not well adapted, however, to photographic work because its lack of

FIG. 23.—Welsbach Lamp and Double-Convex Condensing Lens.

intensity calls for very long exposures of from ten to thirty or more minutes.

Summing up, if we desire a cheap and convenient form of illumination for visual examination with objectives of low and

medium high power, the Welsbach lamp will be found in every way satisfactory; while for the taking of photomicrographs and for examination by high-power objectives, the electric arc lamp and the Nernst lamp should be recommended, bearing in mind that the large arc lamp will yield by far the greater intensity but will, on the other hand, be much more costly. When no suitable electric current is available, the acetylene lamp should be given the preference, provided tanks of acetylene gas can readily be obtained.

Condensers.—Some kind of condensing attachment must be placed between the source of light and the vertical illuminator so that a large portion of the light may be utilized and a beam

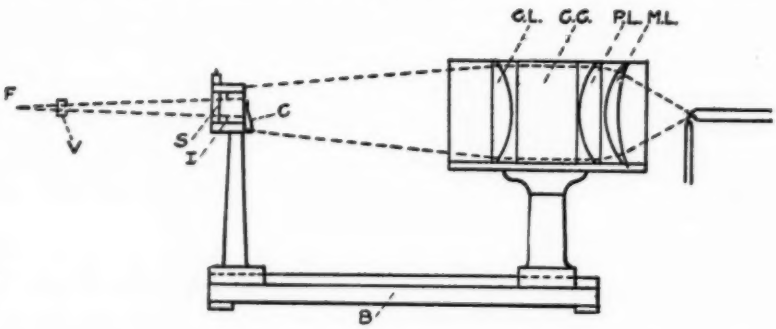


FIG. 24.—Condensing Lenses, Cooling Cell, Iris Diaphragm, Automatic Shutter, and Optical Bench.

of suitable size directed into the illuminator. In the case of light proceeding from a luminous point or at least from a small luminous area, as for instance with the electric arc, at least two lenses or systems of lenses are needed, one system, PL and ML (Fig. 24), placed near the source of light, to collect the divergent rays and convert them into a parallel beam, and a second lens CL placed at some distance from the first, to convert the parallel beam into a converging one. The vertical illuminator should be located at such a distance from the condensing lens that the beam of light will cover a little more than the opening through which it enters the illuminator. A glass cooling cell CC, filled with distilled water or some other suitable liquid, should be placed between the two lenses in order to absorb a large amount of heat and thereby prevent injury to the objective. An iris diaphragm, I, should

also be used to control the amount of light entering the vertical illuminator. This diaphragm should be placed in front of the converging lens and should be provided with clips for holding ground and colored glasses. These various parts should be mounted on a so-called "optical bench" B upon which they can slide.

With a large luminous body such as the Welsbach mantle, a single double-convex lens (Fig. 23) or a bull's eye condenser (plano-convex) is sufficient to collect and condense the necessary amount of light. It should, of course, be placed at the proper distance both from the vertical illuminator and from the source of light. The use of an iris diaphragm attached to the lens or on a separate mount is advisable, since it affords a ready means of controlling the amount of light admitted into the illuminator.

Monochromatic Light.—The different lamps described above all yield, of course, white light, and since the correction even of apochromatic objectives for chromatic aberration is never perfect, it is evident that the use of monochromatic light—i. e., light of one wave length—is preferable, especially for photographing. Monochromatic light may be obtained in two ways: (*a*) by using a source of light actually monochromatic, and (*b*) by causing white light to pass through colored glass screens or colored solutions (light filters), preventing the passage of some undesirable rays. The mercury arc lamp yields a nearly monochromatic light and has been tried by Le Chatelier with satisfactory results. It seems more convenient, however, when monochromatic light is wanted, to use light filters of suitable colors, in which case colored glass screens will be found easier to manipulate than glass cells containing colored solutions.

PHOTOMICROGRAPHIC CAMERAS.

For taking photomicrographs, a light-tight connection should be established between the microscope and camera, both instruments being placed vertically or horizontally (Figs. 25 and 26). Whether to use the camera in a vertical or horizontal position is a debatable and debated question. Among well-known metallographists, Le Chatelier and Martens prefer the horizontal while Osmond and Stead have a strong preference for the vertical position. The latter certainly affords greater stability and eliminates

all danger of heavy specimens slipping while being photographed. It is often said that the vertical position is inconvenient because of the necessity of mounting on a stool for focusing the image on the screen, but the objection appears to me trifling. It is also argued by some that the microscope should be used in a horizontal position

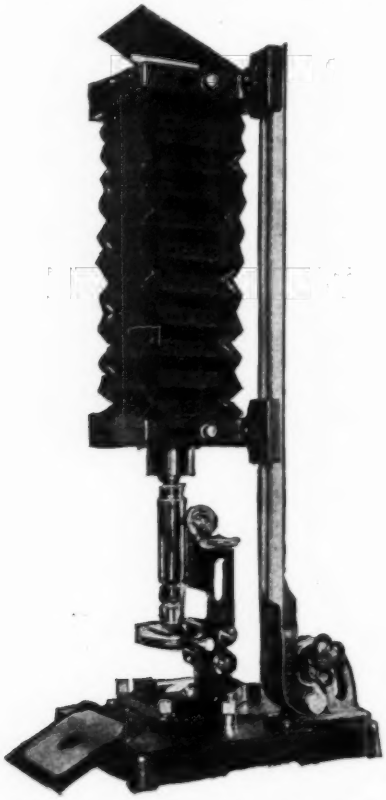


FIG. 25.—Microscope and Camera.
(Vertical position.)

because this makes it possible for the operator to sit while performing his work. This objection also appears to have little weight, for it is not clear why it is more imperative for microscopists to perform their work in a sitting posture than for other laboratory workers, and it is not on record that metallographists are generally persons of such feeble health as to require such solicitude.

The camera illustrated in Figs. 25 and 26 permits the use of plates 4 by 5 ins., and as larger negatives are very seldom, if ever, needed in metallographic work, the use of large, cumbersome and expensive horizontal cameras is not to be recommended.

A focusing glass should be used for the final focusing on the screen and an automatic shutter is of course desirable. The latter may be attached to the camera or mounted separately and placed at a convenient position between the condenser and the vertical illuminator (see Fig. 24).

INVERTED MICROSCOPES.

Le Chatelier was the first to suggest the use of an inverted microscope for the examination of metallic surfaces. In this style of microscope the stage is placed horizontally *above* the objective,

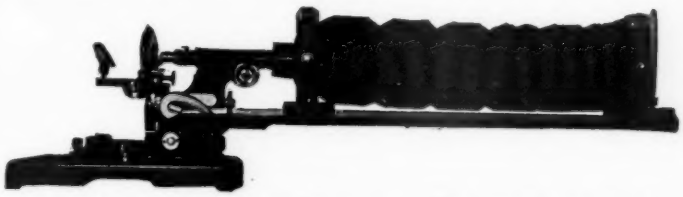


FIG. 26.—Microscope and Camera. (Horizontal position.)

the latter being necessarily pointed upwards (Figs. 27 to 31). Two reflectors at least are necessary: one, R (Fig. 27), to change the horizontal beam of light proceeding from the source of light L (and condenser) into a vertical beam entering the objective and reaching the object O placed on stage S; and a second one, R′, placed below the first to collect the vertical light returned by the object and convert it again into a horizontal beam directed into a camera for photographic work or into a tube provided with an eye-piece for visual examination. By so mounting the reflector R′ that it can be rotated 90° around its vertical axis, the light may at will be directed to the eye or towards the screen of the camera. This method has now been adopted by Le Chatelier. In his first model, however, when it was desired to take a photograph of the object, the reflector R′ was removed from the path of the light, which was thus allowed to reach a photographic plate placed *below*. It is evident that such an arrangement was not convenient.

In case the source of light is placed at a higher level than the reflector R, a third reflector R″ is required to utilize it at the lower level, as clearly shown in Figs. 27 and 28.

The first reflector may be either opaque or transparent; i. e., it may consist of a prism or mirror covering only a portion of the

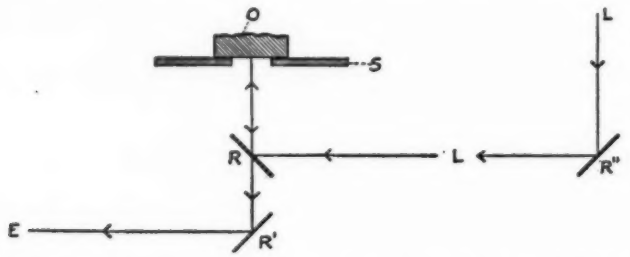


FIG. 27.—Inverted Microscope, showing Reflection of Light from Source to Eye.

objective or it may be a plain glass disc covering the whole aperture. The second reflector should of course be an opaque reflector (prism or mirror) covering at least the whole of the objective

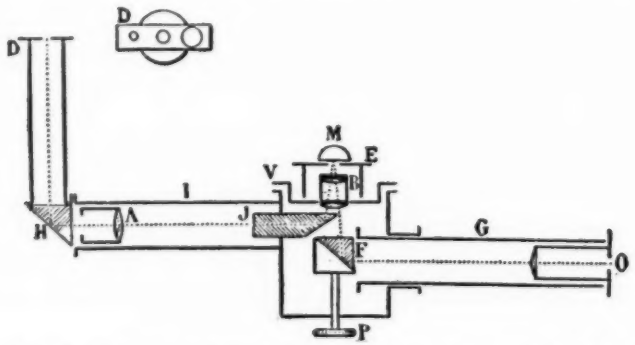


FIG. 28.—Le Chatelier Inverted Microscope, showing Reflection of Light from Source to Eye.

aperture left uncovered by the first reflector, in case the latter is opaque, and the whole aperture in case the first reflector is transparent.

Whether the microscope be inverted or not, the same arguments hold good in regard to the comparative merits of opaque or trans-

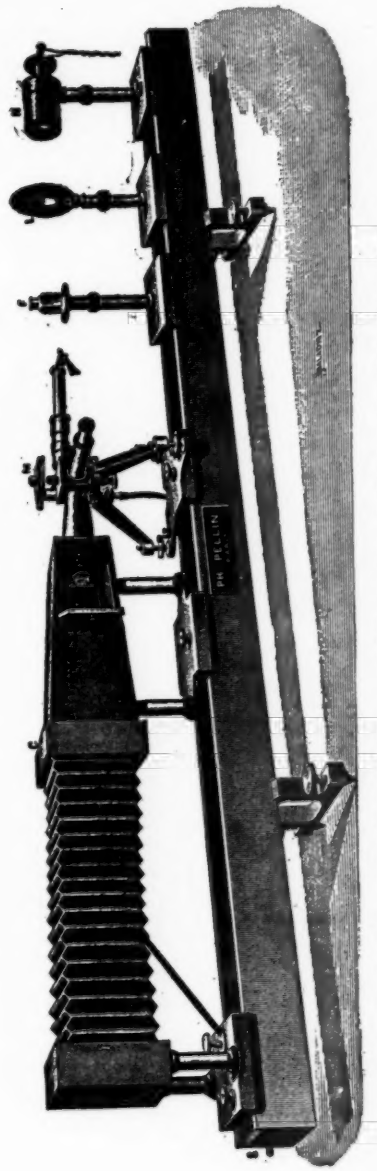


FIG. 29.—Le Chatelier Inverted Microscope and Photographic Attachment.

parent reflector for the first illuminator. I have already expressed my preference in favor of the plain glass reflector.

The Le Chatelier microscope, which is extensively used in France, is clearly illustrated in Figs. 28 and 29. The light is condensed by the lens A and deflected at right angles by the prism J, passes through the objective B and reaches the object M placed on the stage E. The light returned by the object is reflected by the prism F into the tube G and eye-piece O for visual examination, or, by rotating the prism F by means of the milled head P, into

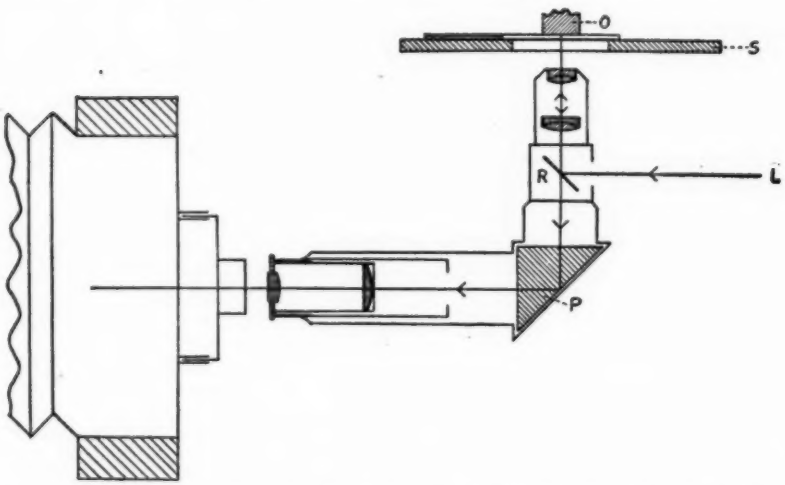


FIG. 30.—Metalloscope, showing Reflection of Light from Source to Eye.

another tube connected with a camera for photographing. It is claimed by some that the inverted type is superior to the ordinary construction because only one side of the metallic samples need be perfectly flat and the necessity of mounting the samples is thus eliminated. With the simple holders described in the foregoing pages this claim loses its weight, for, in the case of iron and steel samples at least, the operation of suspending them to the magnetic holder from below the stage is just as simple as the placing of those samples above and upon the stage, and the insertion of non-magnetic specimens in the holder is a very trifling operation. On the other hand the Le Chatelier type of microscope, as well as some recent modifications of it, are considerably more expensive

than ordinary types and they are not well adapted to the examination of objects by transmitted light. It does not seem clear that so special and expensive a construction is at all needed for successful metallographic work, for there is, of course, no reason why it should be optically superior.

In the inverted type of microscope and photographic attachment illustrated in Figs. 30 and 31, for which the name of metalloscope has been suggested, I have attempted to simplify the construction with corresponding material decrease in price.

The light L is reflected by the glass disc* R into the objective, reaching the object O on the stage S, while the returned light is

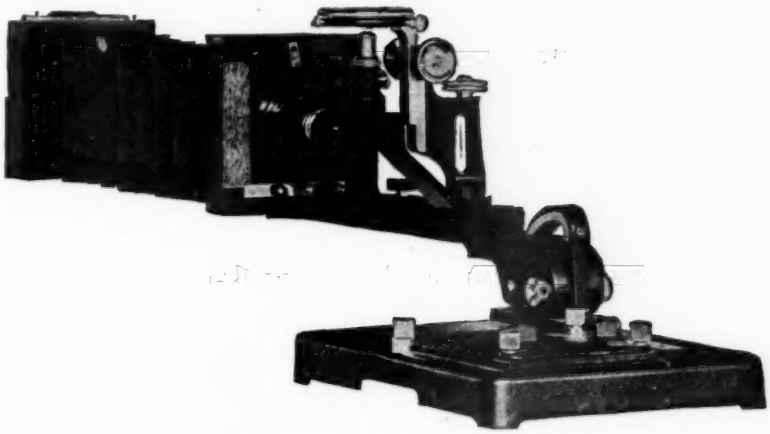


FIG. 31.—Metalloscope and Photographic Attachment.

reflected by the totally reflecting prism P into the tube connected with the camera. For visual examination the bellows of the camera are contracted, affording plenty of room. The microscopic apparatus is firmly attached to the standard of the camera. The stage, which is revolving and provided with centering screws, is of course equipped with both coarse and fine adjustment, and a mechanical stage may readily be substituted for the plain stage.

With this inverted microscope the use of a magnetic holder will also be found very convenient, for the sample is then held

*A reflecting prism may of course be used if preferred.

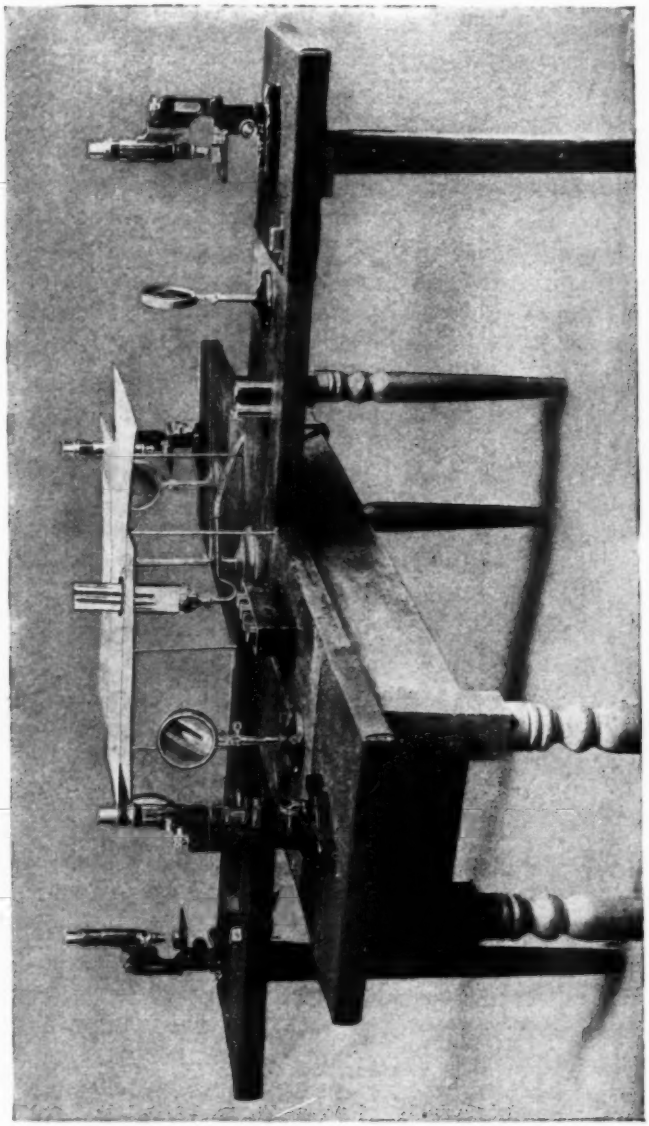


FIG. 32.—Disposition of Microscopes for School Laboratory.

firmly in place instead of resting loosely on the stage, thereby increasing the usefulness of the mechanical stage.

ARRANGEMENT FOR SCHOOL LABORATORIES.

At Harvard University the arrangement briefly described below has been found very satisfactory for the teaching of metallography. Four microscopes, less costly than the one illustrated in Fig. 1 but embodying all essential features, are placed at the four ends of a table built in the form of a cross (Fig. 32). A Welsbach lamp placed at the center of the table provides illumination for the four microscopes. One microscope can be used by a squad of three students and twelve students can work around the table without being in the least in each other's way, one student standing in front of each microscope and one on each side. Two more expensive microscopes are provided on another table connected with photo-cameras and electric arc lamps for photographic work.

The instructor should be provided with a stand, photographic attachment and accessories for his own private use and for the use of advanced students carrying on research work.

The following list of apparatus will be found to include all the essential parts of a very satisfactory laboratory equipment for the teaching of metallography to a class of fifteen students performing their work at the same time:

Four low-price stands provided with vertically movable stages and vertical illuminators.
Three metallurgical stands, high grade, with vertical illuminators.
Seven eye-pieces, 2-in. focal length.
Two eye-pieces, 1-in. focal length.
Seven 16-mm. objectives, short mounted and corrected for uncovered objects.
Two 32-mm. objectives, similarly mounted and corrected.
Two 4-mm. objectives, similarly mounted and corrected.
One 1.9-mm. oil immersion objective, similarly mounted for the use of the instructor and for research work.
One mechanical stage for the instructor's stand.
One Welsbach lamp with glass chimney.
One small electric arc lamp with condenser and iris diaphragm for the students' photographic work.

One Nernst lamp and condenser for similar purpose.
Four large double-convex condensing lenses mounted on adjustable supports.
One large electric arc lamp with optical bench complete, for the use of the instructor and for research work.
Three photomicrographic cameras.
Twelve extra plate holders.
Three focusing glasses.
Seven specimen holders.

The following are suggested as including all the essential parts of a satisfactory equipment for industrial laboratories:

One microscope with vertically movable stage.
One vertical illuminator.
Two specimen holders.
Three objectives respectively of 32-, 16-, and 4-mm. focal length, short mounted and corrected for uncovered objects.
Two eye-pieces, 2- and 1-in. focal length, respectively.
One photomicrographic camera.
One focusing glass.
One large arc lamp with rheostat and optical bench complete, or one small arc lamp with bull's eye condenser and rheostat, or one Nernst lamp with condenser, or one Welsbach lamp with condenser.

I am greatly indebted to Mr. H. M. Boylston of the Division of Mining and Metallurgy, Harvard University, for his most valuable assistance in preparing this paper.

THE 600,000-LB. HYDRAULIC TESTING MACHINE OF THE UNIVERSITY OF WISCONSIN AND ITS CALIBRATION.

By H. F. Moore and M. O. Withey.

In the Materials Testing Laboratory of the University of Wisconsin there has been in service for about three years a 600,000-lb. hydraulic testing machine. Measurement of the load applied by this machine is made by means of a gage attached to a pump which forces oil into the hydraulic cylinder, and the accuracy of this measurement, up to the full capacity of the machine, may be checked at any time by observing the shortening of a hollow steel cylinder under compression or the stretch of a steel eye-bar under tension. In view of the general interest in the question of the reliability of hydraulic testing machines and the many inquiries which have been received concerning this machine, a brief description of it and a discussion of its accuracy and sensitiveness may be of interest.

The load is applied by oil pressure in a double-acting cylinder. The direction of the flow of oil is controlled by four valves placed near a small belt-driven pump which furnishes power. Loads are indicated by Crosby hydraulic pressure gages, one reading to 500 and the other to 2,500 lbs. per sq. in., placed between the pump and the valves. Allowance is made for friction as afterwards noted. (Neither the pump nor the gages are shown in the cuts.)

The rate of flow of oil to the cylinder can be regulated by the needle valve shown in Fig. 1. The main parts of this valve are made of tool steel. A low-pitched thread on the stem and a long taper on the spigot make possible an accurate adjustment of the size of aperture and consequently of the quantity of oil going through the by-pass. The valve is in front of and at a convenient distance below the gage board, so that the operator can easily read the pressures on the gage while turning the valve wheel. It is thus possible to regulate the rate of application of the load and to maintain any load up to the capacity of the machine within 500 lbs. of the desired amount for any length of time. This is a

distinct advantage of this type of machine when measurements of deformation are to be made on the specimen under test.

Fig. 2 shows a cross section of the machine as used for compression tests. Fig. 3 shows a view of the machine with a concrete block in position to be crushed. Referring to Fig. 2, oil is forced into the cylinder (1) below the piston (2), forcing the piston upwards. The stress is transmitted through the piston rod (3) to the table (4). The piston rod is screwed into the table, and a plug (5) is placed over the end of the rod so that the table has a smooth surface. The specimen (6) then takes the stress and transmits it to the bearing plate (7) which has a spherical seat (8) in the

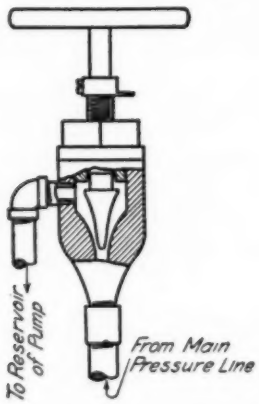


FIG. 1.—Needle Valve on By-Pass.

cross-head (9), this spherical seat minimizing inequalities of distribution of load. The cross-head (9) is fastened by eight removable bolts and nuts (10) to the upright columns (11), which in turn are fastened to the flanges of the cylinder (1) by means of screws (12). The cross-head (9) can be raised or lowered by means of an elevator and hoists shown in Fig. 3 and fastened by bolts to the uprights through holes (14), Fig. 4. The pins for loosening and tightening the capstan-headed nuts on the bolts can also be seen on the right in Fig. 3. The whole machine in compression tests, and also in tension tests, rests on the concrete floor of the pit in which the cylinder is placed. The machine is supported on channels and on wooden blocks, the latter aiding in taking up the shock of recoil when a specimen breaks suddenly.

The adaptation of the machine to cross-bending tests is shown in Fig. 4, which gives a longitudinal section. Fig. 5 shows the machine rigged to test a reinforced concrete tee-beam. In cross-bending tests, oil is admitted above the piston, and as the load is applied the piston moves down. The pipes for admitting oil are shown in Fig. 4, pipe (19) leading oil to the bottom of the cylinder

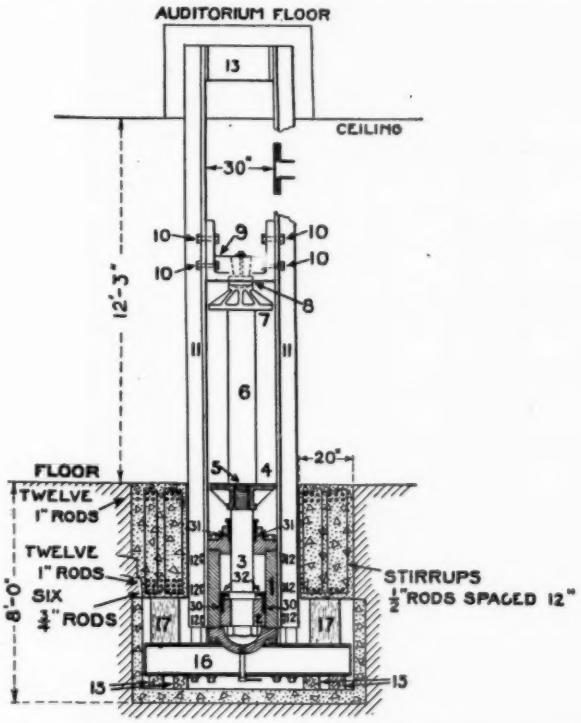


FIG. 2.—Cross Section showing Specimen in Compression.

and pipe (18) to the top. In making a cross-bending test the table (4) is fastened to the cross-head (7), Fig. 4, by four rods (20). The upper compression plate used in the compression rigging (see 7, Fig. 2) is used as this cross-head. From the cross-head, the stress is transmitted to the specimen (21) and through the rocking supports (22) and bearing blocks (23) to the heavy reinforced concrete beam (24). The reaction of the cross-bending load tends to raise the whole central part of the machine, and to pre-

vent this, the uprights are bolted down to channels (see 16, Figs. 2 and 4) through which the force is transmitted to wood blocks (17) and then to the concrete beam.

This concrete beam acts as a double cantilever beam, the tension side being on top, where by reference to Fig. 2 it will be

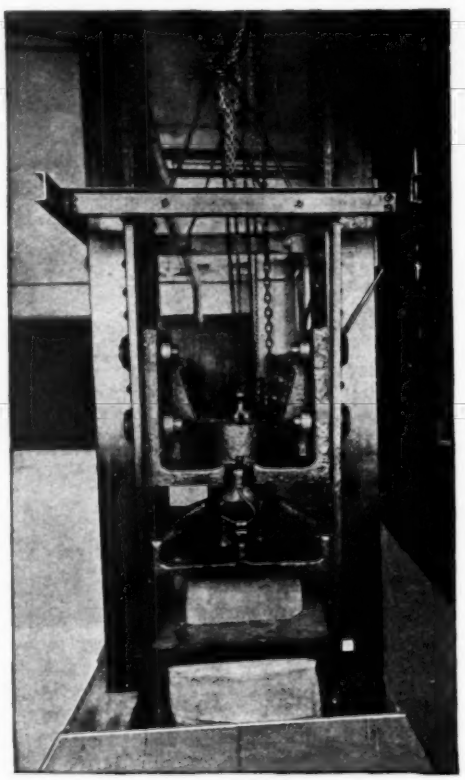


FIG. 3.

seen that the principal reinforcement is placed. The concrete beam is made up of two side beams connected by a slab, shown in longitudinal section in Fig. 4. The main reinforcement in each side of the beam consists of twelve 1-in. rods placed at the top. On the compression side (bottom) is placed a light reinforcement consisting of six $\frac{3}{4}$-in. rods, and on the left side (Fig. 2) where the

projecting footing of the building diminished the width of the concrete in compression, twelve 1-in. rods were placed in the narrow section to help carry the compressive stress. The secondary stresses in both the main beams and in the slab are taken care of by bending some of the main rods and by loop-shaped stirrups

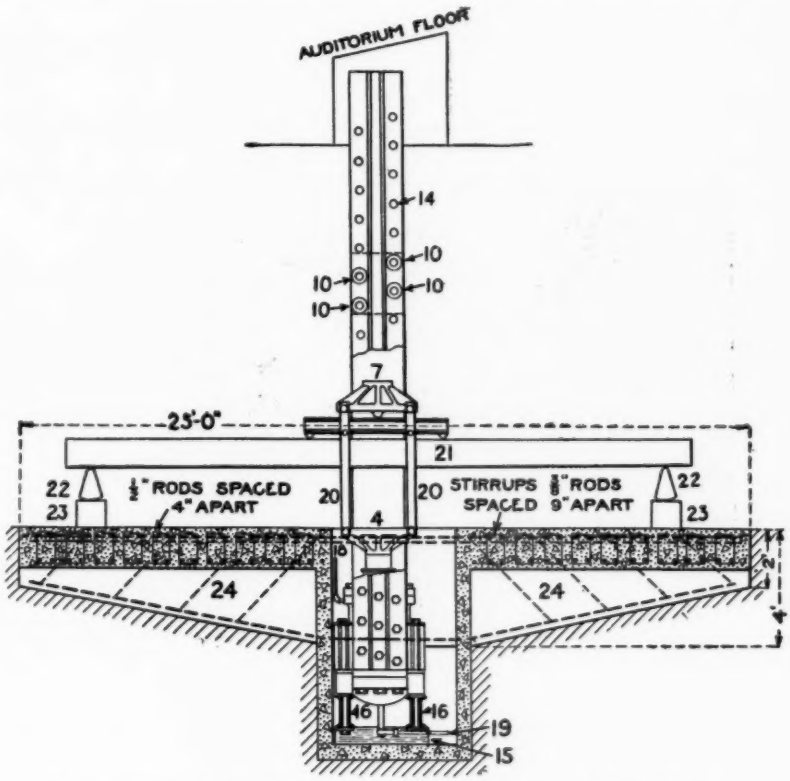


FIG. 4.—Longitudinal Section showing Specimen in Cross Bending.

as shown in the figures. The entire beam weighs about 25 tons, and is made of 1: 2: 4 concrete. The top is faced with 1: 2 mortar. The beam is 4 ft. deep, and the maximum allowable load over a span of 20 ft. is 200,000 lbs.

The adaptation of the machine to tension tests is shown in Fig. 6. Oil is admitted above the piston, and the piston is forced down as the load is applied. Owing to the piston rod the area

under pressure is less in this case than in compression tests, and the maximum load in tension under an oil pressure of 2,250 lbs. per sq. in. is about 470,000 lbs. In making a tension test the plug (5), Fig. 2, is removed and the tension jaw (25), Fig. 6, screwed in its place. This jaw has tapering sides and holds the wedge grips (27). Bolts (29) keep the sides of the jaw from spreading. In the cross-head (9) is a wedge-shaped hole, and in this hole are carried the upper wedge grips (27). When a specimen breaks, these grips are kept from flying out by cross-pieces (28.) From the cross-head (9) the stress is transmitted

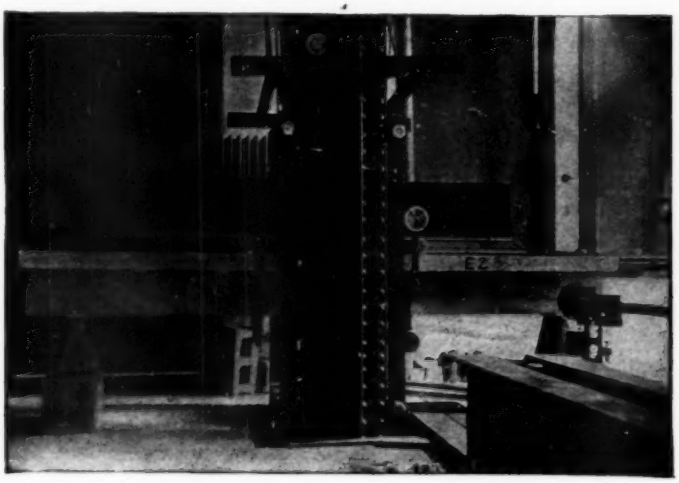


FIG. 5.

through the uprights (11), which are in compression, to the flanges of the cylinder. Fig. 7 shows the machine rigged with clevises gripping the standardized eye-bar. The clevises themselves are steel castings, but the pins are forgings. The lower clevis is threaded to screw into the lower head of the machine, as does the tension jaw (25). The upper end of the upper clevis is formed into a double wedge whose faces have the same inclination to the vertical as do the faces of the slot in the upper head of the machine. It is thus possible to fasten this clevis in place by slipping liners between the faces of the wedge and the slot. This clevis rig has been used more frequently than the wedge grip arrangement.

The capacity of the machine in its present location is:

Compression, specimens up to 12 ft. long, maximum load	600,000 lbs.
Tension, specimens up to about 10 ft. long, maximum load	470,000 lbs.
Cross-bending, specimens up to 20 ft. span, maximum load	200,000 lbs.
Distance between uprights inside rivet heads	28¼ ins.

If the machine should be moved to a location allowing more head room, it would be a comparatively easy matter to lengthen the

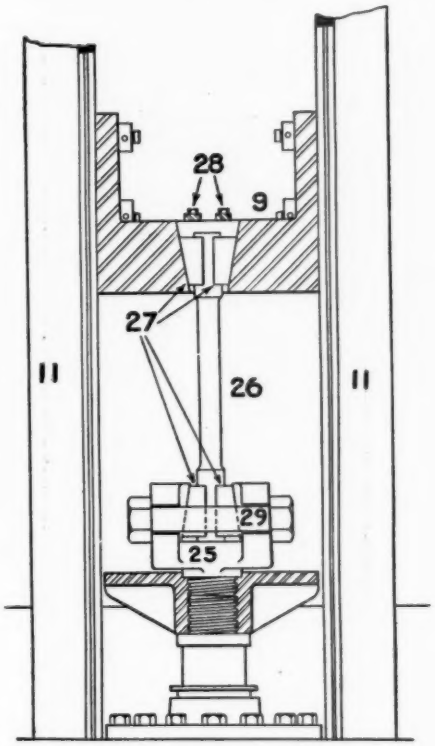


FIG. 6.—Cross Section showing Specimen in Tension.

uprights, and thus to increase the length of specimen which could be tested on the machine. Such an increase in the capacity of a screw-power, lever-weighing machine would be very difficult.

The question of sensitiveness and accuracy of the machine is very important. The chief drawback of the hydraulic-press type of testing machine with a pressure gage to measure the load

is lack of sensitiveness. When this machine is used for compression, and oil is pumped below the piston, utilizing the full piston area, the smallest increment of load which can be detected by the high-pressure gage is about 300 lbs.; if the low-pressure gage is used an increment of load of about 150 lbs. can be detected.

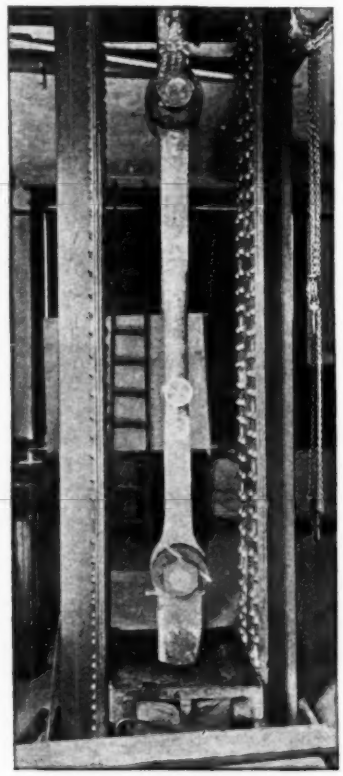


FIG. 7.

The low-pressure gage can be used for loads not greater than 125,000 lbs., and for loads not greater than 50,000 lbs. the portable weighing platform of a Johnson-Olsen beam-testing machine can be placed directly on the piston table of the 600,000-lb. machine. This portable weighing platform can also be used to weigh the end reaction of specimens in cross-bending tests, provided such reaction is not greater than 50,000 lbs.

This machine is frequently calibrated by means of standardized specimens, and its accuracy is largely dependent on the accuracy with which these standardized specimens have been calibrated. These specimens consist of a hollow high-carbon steel cylinder 36 ins. long, with inside and outside diameters of 8 and $9\frac{1}{2}$ ins., respectively; and a forged steel eye-bar 8 ft. long center to center of holes. The central portion of the eye-bar, 30 ins. long, is turned down to a diameter of 4.85 ins. to provide a gage length of 18 ins. for the attachment of extensometers. Both the hollow steel cylinder and the eye-bar were carefully calibrated on the 600,000-lb. Riehlé testing machine at the University of Illinois. (This is a knife-edge-lever machine.) Dial extensometers measuring to one ten-thousandth of an inch and having fixed points of attachment on opposite sides of the specimens are used to measure deformations. In testing the cylinder a bearing block with a spherical seat is always placed at the top of the cylinder to insure as even a bearing as possible. The extensometers on the eye-bar are arranged to measure deformations in the plane of the axes of the supporting pins. From the several sets of readings obtained on the Illinois machine, average load-deformation curves have been plotted for both the cylinder and the eye-bar. Whenever these standard specimens are loaded in the hydraulic machine, gage and deformation readings are taken and the corresponding curves plotted. By determining the equations of the two sets of curves and combining them, equations may be obtained giving the relation between actual loads applied to specimens and gage readings. In tension, compression, or cross-bending tests, the curves which seem to fit the plotted points for the entire range of loads are straight lines.

In order to make determinations of the friction in the hydraulic cylinder and to check the results obtained by calibration with the standard specimens, both high- and low-pressure gages have been calibrated by a lever gage-tester with a capacity of 2,000 lbs. per sq. in. Neither gage reads pressure correctly. However, the curves between gage and gage-tester readings are practically straight lines, the maximum deviation at any point from the straight line value being about 2 per cent.

From a study of the friction in the cylinder it seems evident that the friction developed at the piston packing is the most

important. Frequent calibrations have failed to reveal any large changes in friction due to wear. In this respect the $\frac{3}{4}$-in. square flax packing (30 and 31, Fig. 2) has proven to be very serviceable. From experience with the machine it seems improbable that the friction will ever change as much as 1,000 lbs. during a series of heavy tests extending over a period of six months. Of course any marked change can be readily detected by the reading of the low-pressure gage while the piston is in motion. The maximum change in friction during the entire length of stroke is less than 1,200 lbs. for the speeds ordinarily used in testing. There is, however, considerable difference in friction for high piston speeds. For one portion of the stroke the friction varied from 2,000 lbs. at a piston speed of 0.06 in. per minute to 5,000 lbs. at a speed of 0.4 in. per minute. Computations show that the friction developed when oil is pumped to the under side of the piston decreases as the pressure increases, while the reverse is true when oil is pumped to the upper side of the piston. The former condition is doubtless due to the expansion of the piston packing brought about by the downward pressure of the oil on the gland (32), Fig. 2. The variation of the friction seems to be linear in either case. The maximum value as computed at the maximum tensile load is not over 16,000 lbs.

From the results of calibrations and tests it is believed that the probable error of results obtained in tension, compression and cross-bending tests is not over 3 per cent. when the load is over 50,000 lbs.

Attention is called to the fact that a hydraulic press machine with a gage automatically indicates the load. Such a self-indicating machine is more convenient to handle than one in which a weighing beam must be balanced before the load can be read.

The hydraulic cylinder of the machine was made by R. D. Wood and Company of Philadelphia, the steel castings were made by the Falk Company of Milwaukee, the structural steel uprights were made by the Wisconsin Bridge and Iron Company of Milwaukee, and the machine was erected under the direction of the Superintendent of Shops of the University of Wisconsin. The total cost was about $3,500. So far the machine has proven a very satisfactory piece of apparatus. It can be adjusted easily and quickly to perform any test within its capacity, and it gives results of sufficient accuracy for the class of work for which it was designed.

DISCUSSION.

THE PRESIDENT.—The Society is to be congratulated upon this paper, which is in so many respects a model paper in the frankness and clearness with which the authors have pointed out possible improvements on their machine. This procedure of pointing out possible improvements is one which we must all applaud as paving the way for improvements. **The President.**

We can hardly emphasize too often the greater importance of accuracy than of sensitiveness. We all know it, but often overlook it. A simple illustration may tend to fix the relative value of these two factors in our minds. If I have a dollar watch with a second hand and a chronometer without a second hand, the dollar watch would be much more sensitive than the chronometer, though of course much less trustworthy. For boiling an egg or timing a pulse, the dollar watch would be the better; for catching a train and for the great majority of purposes, the chronometer would be the better. There would not be much question as to which would be the better instrument to possess. This paper is now open for discussion. There are many present who have had experience with testing machines.

MR. LEONARD WALDO.—I think in this age of structural engineering progress we cannot keep too constantly in mind the necessity of testing full-size members. It is always a pleasure to hear of a new machine of such a high capacity as 600,000 lbs. I should like to ask what the effect of the recoil of such heavy loads is, and what provision is made for taking it up. **Mr. Waldo.**

MR. H. F. MOORE.—I can answer that question by saying that I have not myself witnessed any test which strained the machine very hard under the recoil due to the breaking of specimens. Such tests have been made, and Professor Withey, who handled the machine, told me that no injurious effects had yet been observed. The provision for taking up the recoil is merely the placing of wooden blocks so as to be compressed across the grain by the recoil. The foundation on which the machine rests and the wooden blocks have apparently so far taken up the recoil without **Mr. Moore.**

Mr. Moore. any serious damage to the machine. It will be noted that there are no delicate parts on the machine itself to be injured by recoil, so that more shock is probably allowable than in the case of a machine where the knife edges would be hammered by the recoil. The pressure gage is safeguarded against sudden release of load by a ball release valve.

Mr. Macgregor. MR. J. S. MACGREGOR.—During the reading of this paper it occurred to me that the accuracy of this machine is a very important matter. Many machines of large capacity are designed without taking the required percentage of accuracy into consideration. I am satisfied that a machine of this type is amply accurate enough for the work which it is designed to do.

SOME TESTING-LABORATORY ACCESSORIES.

By J. M. Porter.

Many of the testing laboratories of to-day, and especially those connected with educational institutions, have a large and growing assortment of apparatus for the measurement of the deformation of material under stress, grips or jaws for holding the material while the stress is applied, molds for special cement and concrete work, and other accessories for use in special cases.

Many of these instruments that the author has seen have been built upon incorrect designs, although results obtained by their use may be practically correct. The writer has in mind the ordinary form of compressometer such as is used in concrete work, in which the two rings that surround the specimen have each four points in contact with the specimen; also the common form of fiber extensometer for concrete beam work, in which there are two solid or rigid frames surrounding the specimen, each of which are attached thereto by four points of contact; and also a form of torsion apparatus in which the instrument has a V-shaped bearing on the specimen of an inch or more in length. These instruments are quite common and can be seen upon a visit to almost any testing laboratory, and they are illustrated and described in almost any instrument maker's catalog.

The writer recognizes the absurdity of useless refinement in the construction of instruments, but he also recognizes the absurdity of recording readings of instruments whose design is not in keeping with such refinement. In the type of compressometer cited above, the readings are generally taken to the nearest ten-thousandth of an inch, and the mean reading of two micrometer screws or dials is taken as the deformation of the material. In fact, however, the deformation recorded is the deformation of the material plus or minus the deformation of the surrounding rings. The four points of attachment must always remain in the same plane, otherwise the ring is distorted or the points slip on the specimen. Three points are sufficient to determine a plane, and four points of contact or attachment are of no benefit whatever, and in

fact are a detriment. This is also the argument against the rigid frame with four points of contact so commonly used in the fiber-deformation determinations of reinforced concrete work. The four-point attachment is wrong in principle, and the results obtained from instruments so constructed are incorrect when readings are taken as low as one ten-thousandth of an inch. The torsion indicator described above is also wrong in principle, as the actual gage length of the specimen is unknown.

The following instruments have been in use for several

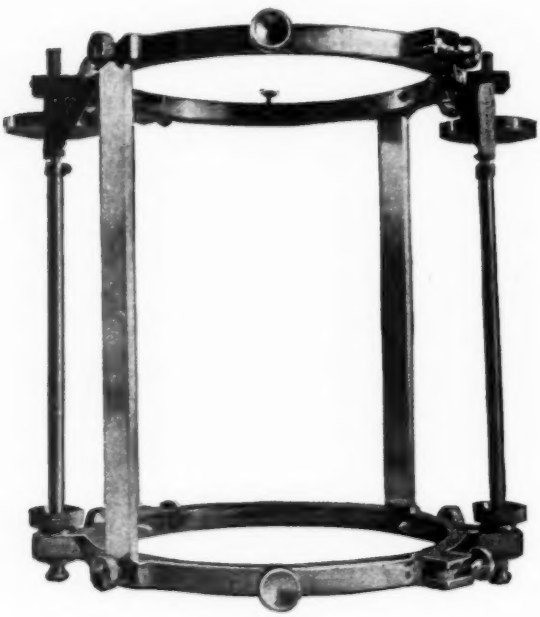


FIG. 1.—Compressometer.

years in the laboratories connected with the Department of Civil Engineering, Lafayette College. They are the results of the combined talents of Mr. A. T. Goldbeck, Instructor in Civil Engineering, Mr. M. L. West, mechanician, and the writer, and were built in the shop connected with the Department. They are believed to have been built on as nearly correct principles as possible and also to possess certain features that enable ease of operation and quick and accurate results.

Compressometer (Fig. 1).—This instrument consists of an upper and lower ring, each in two sections. Each half of the upper ring contains one micrometer screw reading to one ten-thousandth of an inch, and is attached to the lower half by a detachable distance bar. Each half of the lower ring contains an adjustable rod attached by a fiber ball acting as a universal joint and at the same time as an insulator. Each ring contains three screws for attachment to the specimen, two in one half and one in the

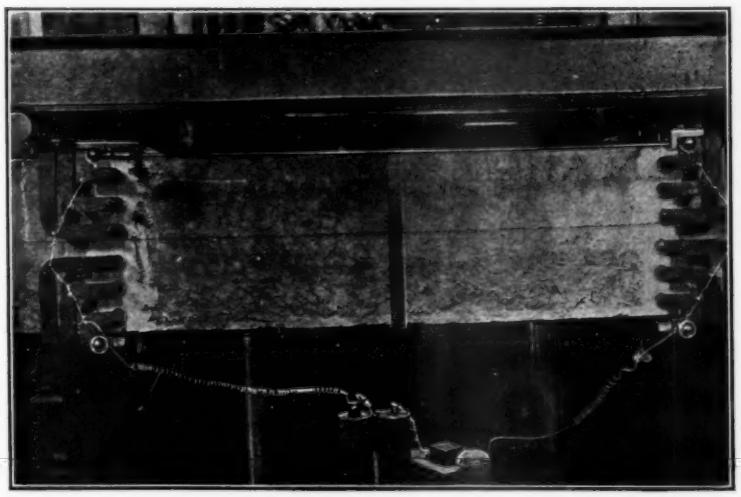


FIG. 2.—Strainometer attached to Concrete Beam.

other. There is nothing especially noteworthy in this instrument except the three attachment screws, the distance bar, and the adjustable rods combined with the ball and socket. The two slow motion screws on the top of the adjustable rods are quite common. The cost of labor and material for two of these instruments was $90.00. This instrument can also be used as an extensometer.

Strainometer (Figs. 2 and 3).—This apparatus was designed to determine fiber deformations in reinforced concrete beams, and consists of twelve U-clamps, six on each side of the center of span, with three above and three below the center depth of the beam. The ends of the clamps are bent at right angles to their planes and contain a set screw having a wing nut at one

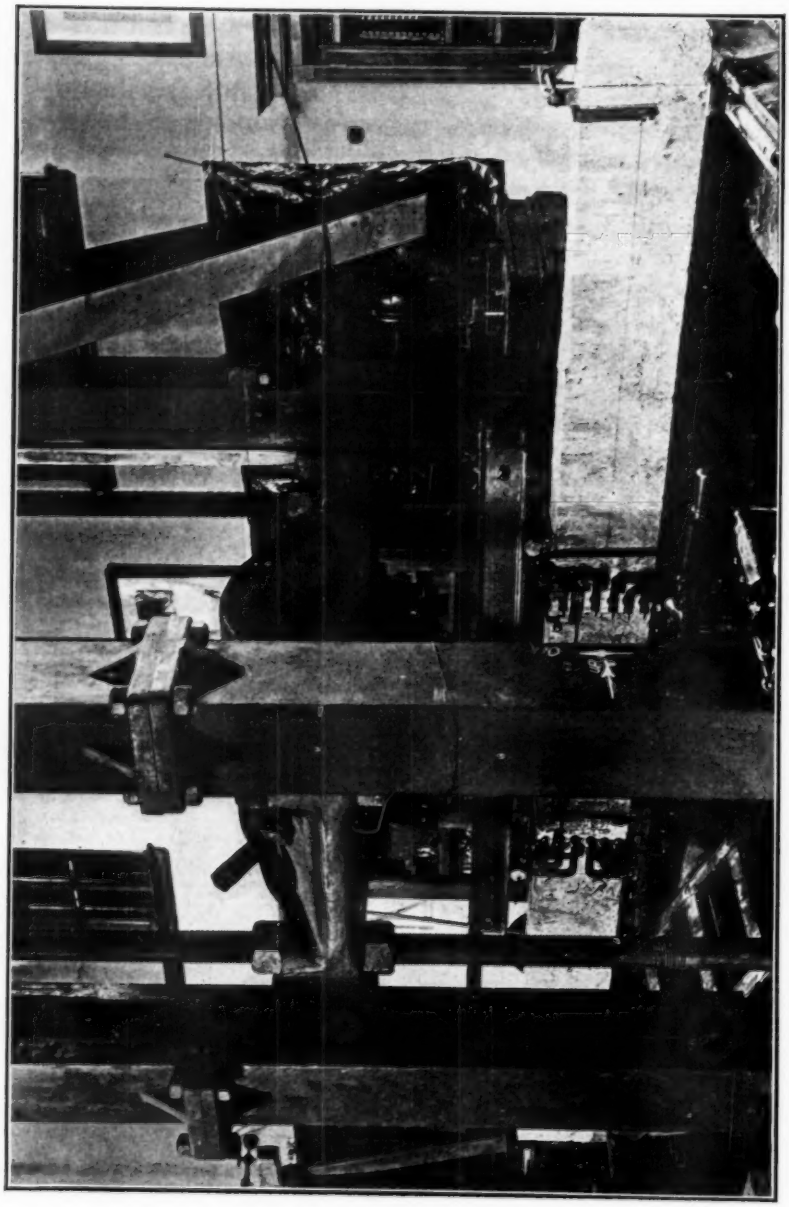


FIG. 3.—Concrete Beam with Strainometer attached ready for Testing.

end and a cup cap at the other. The sets of six top and six bottom clamps are each connected by distance bars, giving a gage length of 36 ins. between cups. A steel ball 1 in. in diameter is placed between each cup and the beam, and clamped thereto by means of the screw. There are then twelve balls on each side of the beam, in six horizontal rows of two each. This apparatus is used on the standard beam 8 ins. wide and 11 ins. total depth, or 10 ins. effective depth. The top row of balls is placed 1 in. from the

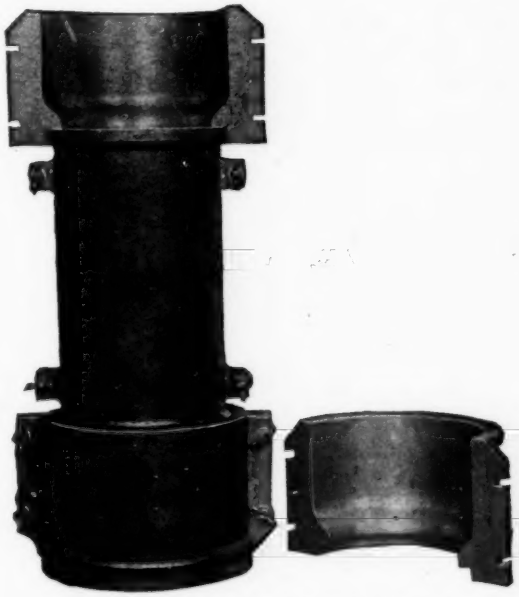


FIG. 4.—Mold for Tension Specimens.

top of the beam, while the lower row is 1 in. from the bottom and in the plane of the reinforcement, the intervening rows being 1.8 ins. between centers. In addition to the above there are four special frames with 1-in. bronze balls permanently attached to their ends, which are placed across the beam in line with the vertical row of balls in such a position that the centers of the balls lie in the horizontal plane through the top and bottom of the beam. This adjustment is accomplished by means of set screws in contact with the top and bottom surfaces of the beam.

This frame is kept in contact with the beam by means of special U-clamps.

The removal of the distance bars allows any ball to move in

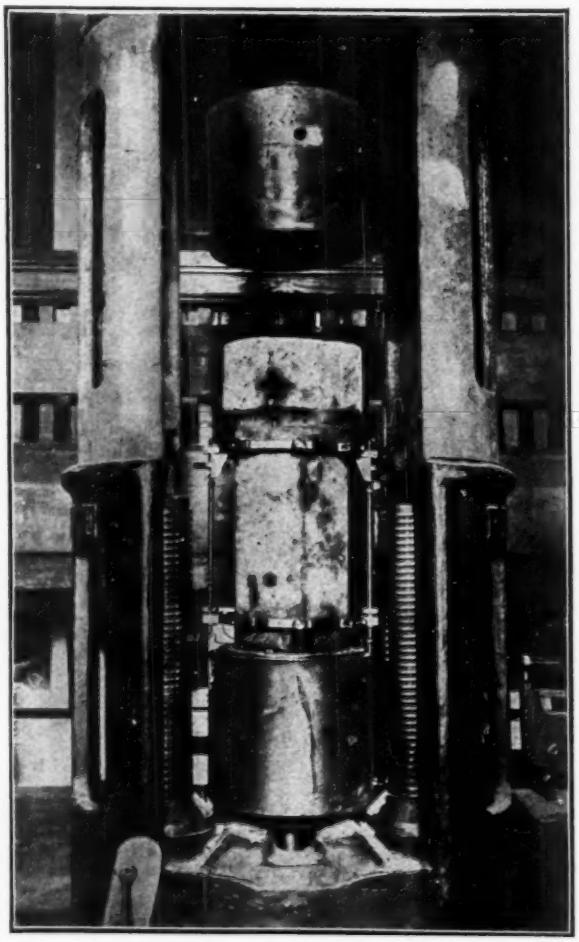


FIG. 5.—Tension Specimen with Extensometer attached and Upper Pulling Head ready to be connected.

any direction entirely independent of the movement of others. As this apparatus is used only with a two-point loading, which points are outside and symmetrical with the row of balls, any and

all changes in distance between balls in the same horizontal row must be due to the fiber deformation.

This deformation is measured by means of a special micrometer, reading to one ten-thousandth of an inch, attached to a steel

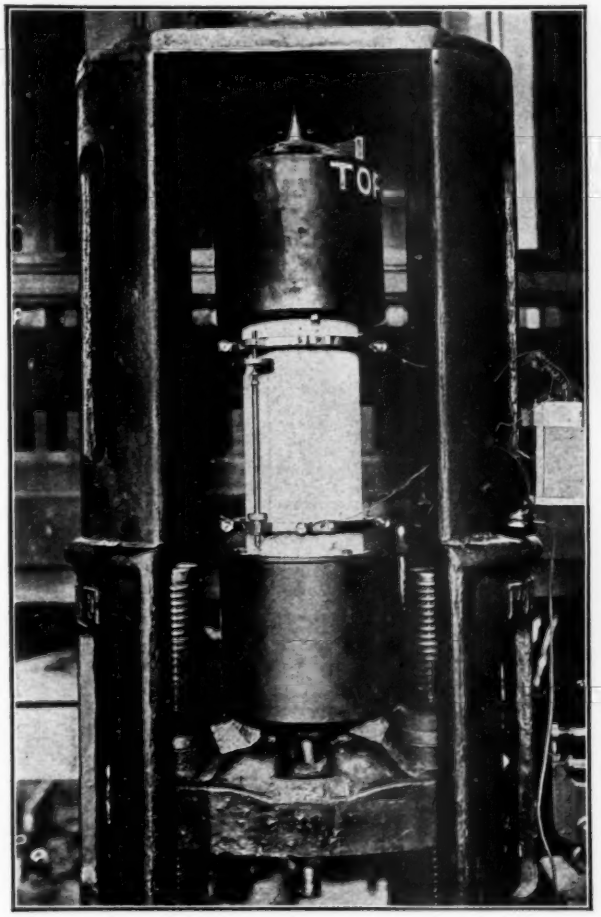


FIG. 6.—Tension Specimen ready for Testing.

tubing the ends of which are so arranged that when resting on the steel balls the prolongation of the axis of the tube coincides with the diameters of the balls.

The ends of the tube are insulated from its supports and the

whole apparatus is electrically connected with a battery and telephone receiver or a voltmeter in circuit.

The circuit is not closed until the micrometer touches one ball and the other end of the tube, which projects slightly beyond the support, touches the other ball. This is accomplished by the movement of the micrometer, and the closing of the circuit is immediately indicated by means of the receiver or the voltmeter. The micrometer tube is removed from one set of balls to the next set and readings taken. Two micrometer tubes are used, one on each side of the beam, and simultaneous readings are taken by the observers.

The special micrometer referred to was designed by Mr. Goldbeck, and consists of a rod with forty threads per inch, carrying a cylindrical nut, the outside of which has fifty threads per inch, and which carries in turn another cylindrical nut which is prevented from turning by having a square bearing through which the prolongation of the original rod passes. One revolution of the first nut will give an advance of 0.025 in., during which time the last nut will recede 0.02 in., so that the total advancement will be the difference, or 0.005 in. As the head of the first nut is divided into fifty parts, each part will represent 0.0001 in.

This micrometer has been checked with a Ewing extensometer and was found to give correct readings. This form of micrometer has no advantage over the ordinary form of forty threads with head divided into two hundred and fifty parts, except that the head is smaller in diameter, being $\frac{13}{16}$ in. while the other is about $2\frac{1}{2}$ ins. The ordinary form of micrometer could not have been applied to this apparatus owing to the size of balls used. In actual use, however, the ordinary B. & S. inside micrometer reading to one one-thousandth of an inch and by estimation to one ten-thousandth of an inch without electrical contact was found to give satisfactory results and to effect a considerable saving in time, except at the extreme top and bottom balls where electrical contact is necessary.

The advantages of this apparatus are as follows: It can be applied to any standard beam without special attachments being made during or after molding, such as the insertion of plugs, nails, etc.; a comparatively large number of measurements can be taken throughout the depth of the beam, and all of the same

gage length; the measurements taken are always between fixed points relative to the beam, whatever the motion of the beam may be; and it also enables top and bottom fiber deformations to be measured.

Concrete Tension Molds and Pulling Heads.—Comparatively

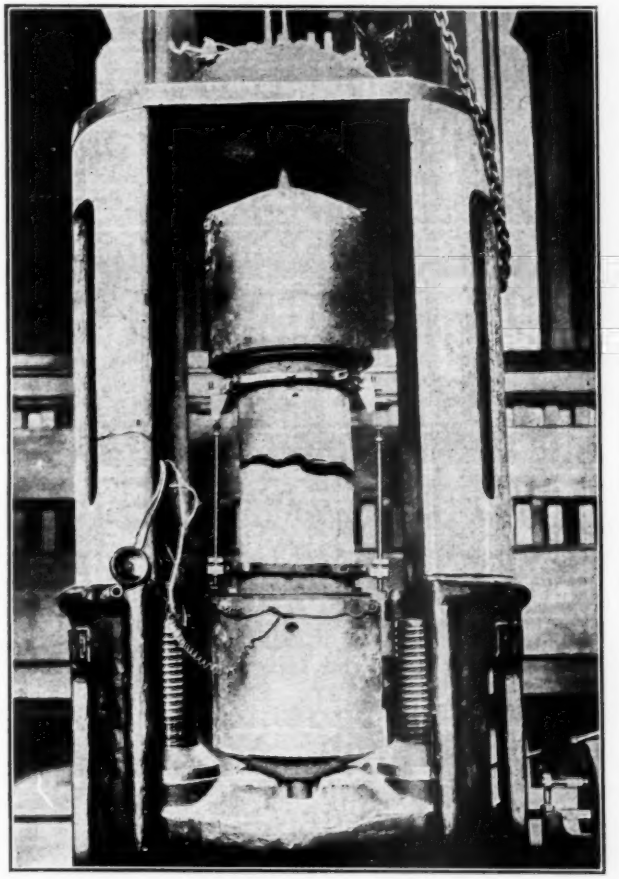


FIG. 7.—Tension Specimen after Failure.

few tension tests have been made on concrete, owing possibly to the difficulty of obtaining a satisfactory form of specimen and a means of applying the load. The apparatus now to be described has been in use for about two years and has given satisfactory results.

Fig. 4 shows the form of mold used; the cylindrical part is 8 ins. in diameter and 16 ins. high. This mold may also be used for molding compression specimens.

Fig. 5 shows the specimen in the testing machine with the lower end in the pulling head, extensometer attached, and the upper pulling head ready to be connected.

The pulling heads consist of a cast-iron cylinder closed at one end, through which passes a pulling bar with a ball joint at one end; the other end of this bar is gripped by the jaws of the testing machine. This arrangement gives a straight pull on

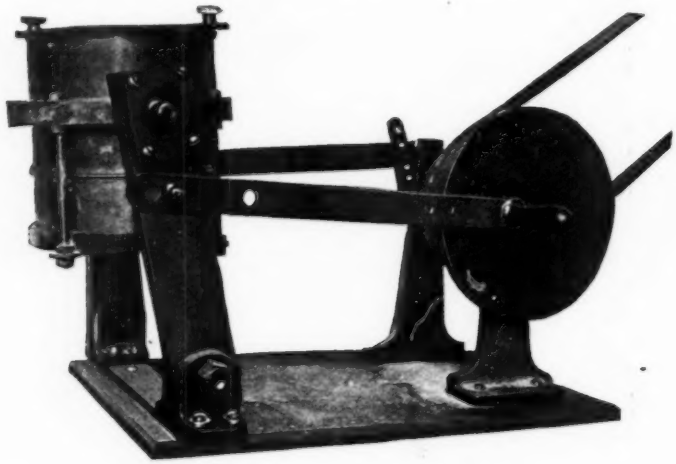


FIG. 8.—Cement Sieving Machine.

the specimen. The open ends of the cylindrical heads are threaded and contain a threaded split-ring bushing, the inside of which has the reverse form of the shoulder on the specimen.

Fig. 6 shows the specimen ready for testing, with all attachments made. The split-ring bushings can be seen, as well as the tap bolt holding them together.

Fig. 7 shows the broken specimen.

Two or more of the cylindrical parts of the molds may be placed one on top of the other, so that a specimen of any desired length can be made. In molding it is necessary to remove the upper part of the mold as soon as possible, in order to avoid initial cracks due to the contraction of the concrete while setting. With

this apparatus the specimens are easily molded, and are of a sufficient size to give a fair idea of the quality of the material. They are easily inserted in the testing machine, and with ball and socket pulling heads insuring a straight pull, the results should be as accurate as tension tests on other material.

FIG. 9.—Ball and Socket Pulling Heads.

One possible objection to this form of mold is that the specimen is molded end on, while in beam work the specimen is molded flat. What difference this would make in the results the writer is not prepared to say.

Cement Sieving Machine (Fig. 8).—There are many different

styles of cement sieving machines in use to-day, giving various degrees of success. The one illustrated has been in use for a number of years and is believed to imitate the proper hand motion as nearly as it is possible to do so by mechanical means.

The apparatus consists of two rocker arms supporting a ring frame which surrounds and supports the sieves and receiving pan. The far end of the ring is attached to the rocker arm by a double hinge in such a manner that the ring may have a rotary motion in the plane of the arm and also at right angles to the same, but no longitudinal movement. The near end of the frame is supported by a short shaft projecting through a ball which forms part of a ball and socket bearing, thus allowing rotary as well as longitudinal motion. The two rocker arms are driven by means of short connecting rods attached to cranks having different

FIG. 10.—End Supports for Transverse Tests.

throws, the near one being 1½ ins. and the far one 2 ins. The far crank is set with about 80° angular advance. The apparatus is driven by belt at 170 revolutions per minute, and accomplishes results in about one-third the time required by hand.

This apparatus is the result of much experimental work, and the throw and advance of the cranks were determined from results so obtained. While the apparatus shown is an experimental one and has given very good results, it can be improved in many details. Some of the improvements the writer has in mind are to rotate the sieves about their own vertical axis, to shorten the connecting rods, and to add another set of rocker arms and sieves to the right of the shaft and drive them from the same cranks.

Pulling Heads.—To obtain correct results in simple tension or compression tests, it is important that the load be applied to the specimen in such a manner as to avoid bending stresses. The parallelism of the heads of the ordinary testing machine cannot be depended upon to accomplish this result.

The apparatus shown in Fig. 9 will give a straight pull on the specimen and will practically eliminate all bending stresses. It consists of two ball and socket pulling heads, so arranged that they may be inserted in the V-grips of the testing machine. The sockets are provided with detachable screw bushings made to fit various sizes of screw-end specimens.

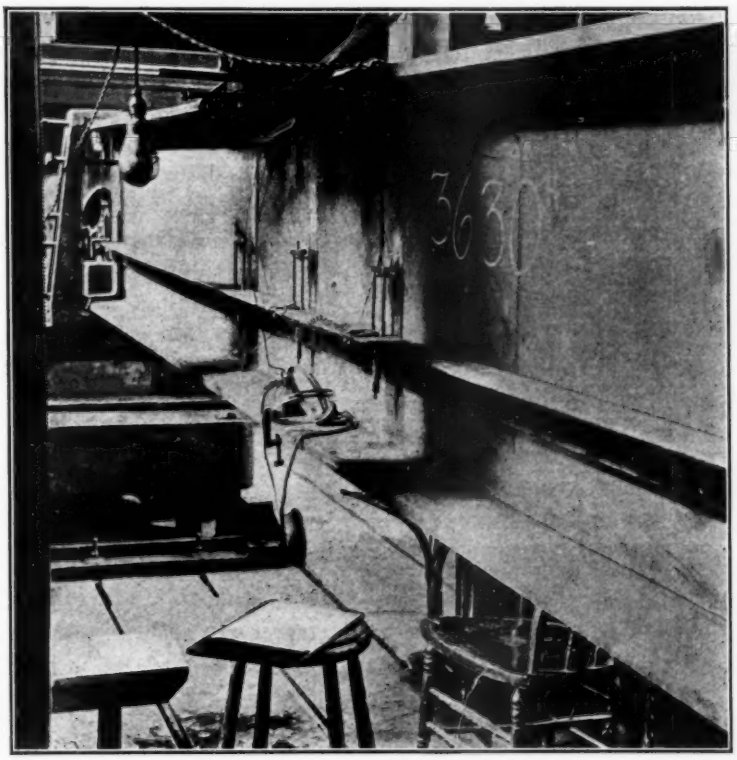


FIG. 11.—Deflectometer, showing Attachment of Micrometers.

The main feature of this particular apparatus is the ease with which it can be inserted in the machine. It does not require any special blocks to fit the head of a particular machine, but can be applied to any machine having the ordinary V-grips.

End Supports for Transverse Tests.—The form or type of end support used in making transverse tests may greatly influence

the result. This is especially true in the case of cast iron, where the span is generally short and the cross section of the specimen small. The common flat specimen of cast iron quite frequently has more or less warped surfaces, and when used with the ordinary more or less rigid V-shaped end-blocks, a variety of results will follow.

The apparatus shown in Fig. 10 consists of two blocks of tetrahedral form, resting on two rectangular blocks that may be clamped a definite distance apart. The lower edge of the tetrahedral block is concentric with the upper edge, which is in a plane at right angles to a plane containing the former. The action of this apparatus is in all respects similar to that of a ball and socket joint, but has the advantage of being less expensive to construct.

Deflectometer.—A common method of measuring the deflection of beams of long spans is to attach a steel scale to the beam at the point of required deflection, and read the deflection from a wire or fine silk thread attached to, or from a bar supported at a point in the neutral axis of the beam over the points of support. Dials worked by silk-covered wire have also been used, but the writer has been unable to obtain satisfactory results with wire or thread when used to transmit deformations, although he understands that others have been quite successful.

Last summer a number of tests on large I-beams were made under the direction of the writer, and it was desirable that the deflections be measured with unusual accuracy. The following scheme, as illustrated in Figs. 11 and 12, was developed and used with success:

Through the neutral axis of the beam and in line with each end support, a through bolt was clamped projecting about $1\frac{1}{2}$ ins. on each side of the web. From a small punch mark at each side of these bolts, by means of a hanger, a $3\frac{1}{2}$ by $3\frac{1}{2}$-in. angle was supported on each side of the beam. At midspan, and at a fixed distance on each side of midspan in line with the neutral axis, other through bolts were placed from which hung special micrometers passing through slots in the horizontal leg of the angle. Pins surrounded with fiber bushings were attached to the outstanding leg of the angle in line with the micrometer screws, and the whole apparatus was electrically connected with a battery and telephone receiver in circuit. Direct readings were taken

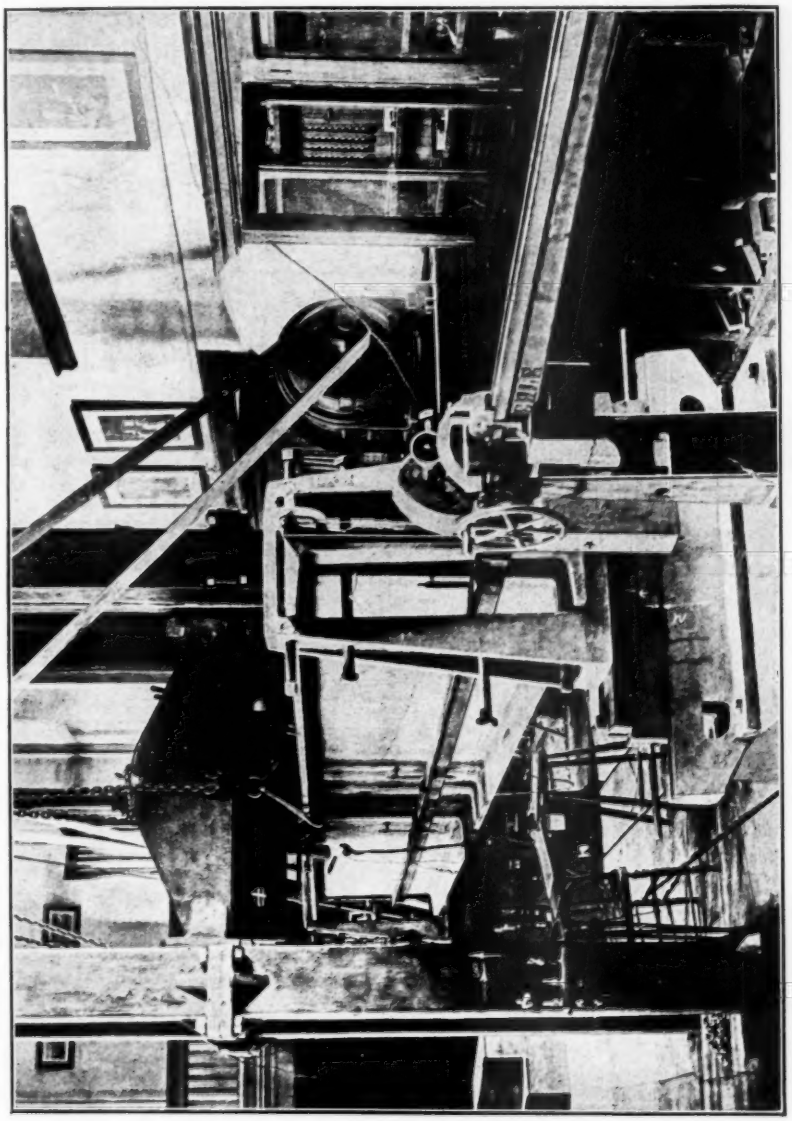


FIG. 12.—Deflectometer attached to Beam.

from the micrometers on each side of the beam by two observers to one one-thousandth of an inch and by estimation to one ten-thousandth of an inch. Each angle weighed about 140 lbs., and it was found that a movement of about $\frac{1}{4}$ in. from normal position was required before a change in the micrometer readings of one one-thousandth of an inch would occur.

This apparatus was used on spans of 20 ft. and the results were entirely satisfactory.

Torsion Apparatus.—This apparatus consists of two rings,

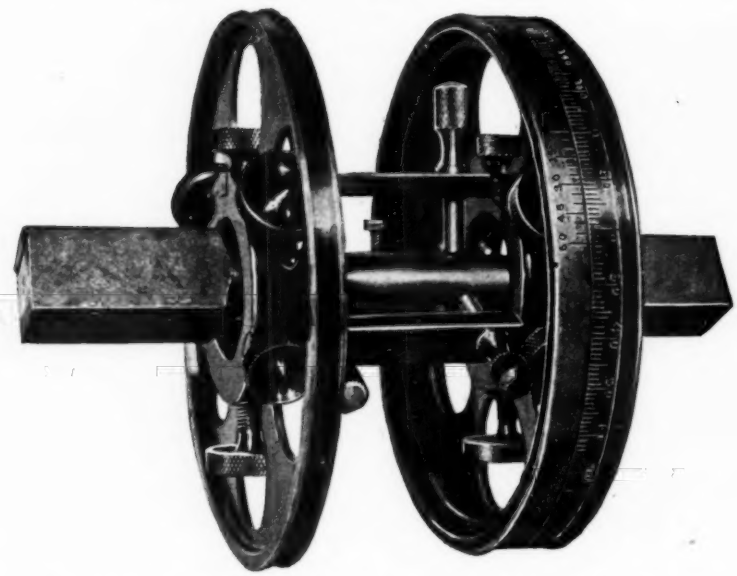


FIG. 13.—Torsion Apparatus, with Specimen attached; Distance Bars in place.

containing three set screws each, for attaching the rings to the specimen. These rings are connected by distance bars containing two studs for centering the specimen. These studs can be varied in length so as to accommodate specimens of various diameters. Fig. 13 shows the apparatus attached to the specimen, and Fig. 14 shows the same apparatus with the distance bars removed, ready to be inserted in the machine.

The right-hand ring, as shown in Fig. 13, is graduated in degrees and carries a concentric ring on a ball bearing con-

taining a vernier reading to five minutes of arc. To the left-hand ring is attached a finger connecting it with and conveying its motion to the concentric ring. The connection of this finger with the concentric ring is made by means of a ball joint, thus allowing for the change of length of the specimen when under stress. This connection is also provided with a slow-motion screw to enable the vernier to be set at zero at the beginning of the test.

FIG. 14.—Torsion Apparatus; Distance Bars removed for Insertion in Machine.

Each ring is supplied with a groove for the thread of an autographic apparatus.

The specimen with the apparatus attached and distance bars removed is placed in the machine, and as the stress is applied the deformation angle for the given gage length may be read directly from the vernier. The apparatus shown has a gage length of 3 ins. and was designed for a square-end specimen not more than $1\frac{1}{4}$ ins. square. It could be used, however, for any gage length with the addition of new gage bars and a new finger.

The advantages of this instrument are that it is compact, is easily applied to the specimen, has a definite gage length, and gives correct readings until the deformation of the specimen is such that the original planes containing the set screws of the rings are no longer parallel.

In conclusion, the writer wishes to state that no arrangements have been made with any instrument maker for the manufacture of these instruments, and if any one wishes to have them manufactured they are at liberty to do so; and furthermore, the writer would be pleased to furnish them with the necessary detail drawings.

APPARATUS FOR REPEATED LOADS ON CONCRETE CYLINDERS AND A TYPICAL RESULT.

By H. C. Berry.

The apparatus for the repetition of loads on concrete cylinders was devised by the writer and built under his direction in the shop of the Civil Engineering Department of the University of Pennsylvania. The investigation was undertaken with a view to determine the percentage of the ultimate strength of concrete that might be repeated an unlimited number of times and to study the elastic behavior of the specimens as the number of loadings increased. The first object entails the determination of a curve to show the relation between the percentage of ultimate strength and the number of repetitions that will ultimately cause failure of the specimen. The second object may show us whether there is, as has been indicated, a limit to the "set" of concrete as the number of repetitions is increased. In other words, is there a certain amount of deformation that a specimen of concrete will take under repetition of load after which there is little or no effect from further applications of the same load, or does this "set" continue to increase with repetitions of the load? And if the latter is the true supposition, at what time does this increase in the deformation cease to be a real "set," and disintegration begin?

The specimen adopted for this work is the 8-in. cylinder 16 ins. high, which is gradually becoming the standard for compression tests. Consequently the results may be compared with the results from the regular compression tests without any assumption as to the effect of size. The large size also tends to minimize the effects of slight variations in the mixing, molding, and placing of the individual specimens.

The 8-in. cylinder, 50 sq. ins. in area, made it necessary to design an apparatus of large capacity, and since we wished to adapt the mechanism previously used in the repeated load test on concrete beams, described in the *Proceedings*, 1908, Vol. VIII, page 454, in which 20,000-lb. proving levers were used to apply the load, it was necessary to compound the lever system. As shown in

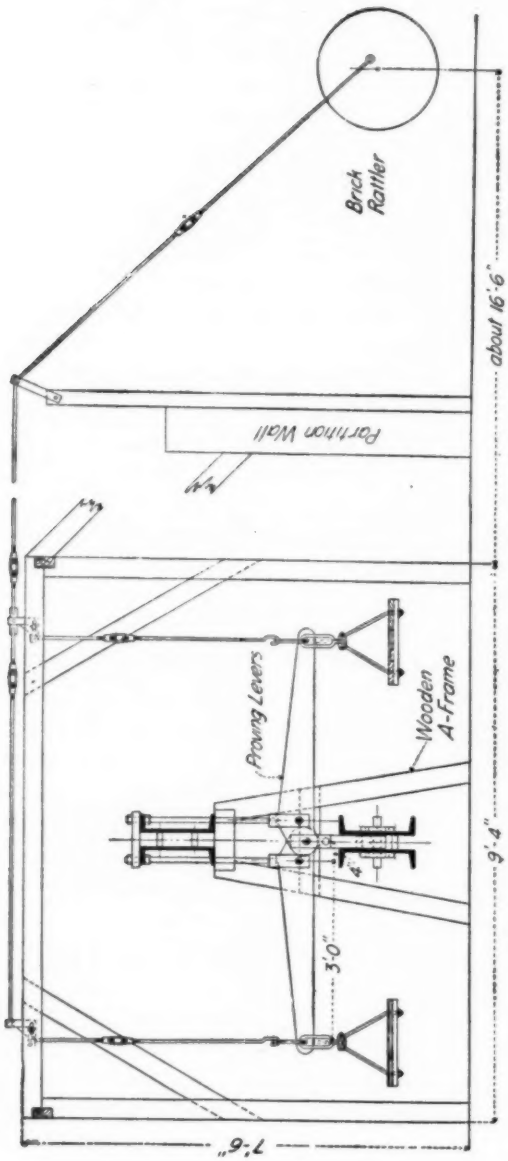


FIG. 1.—Machine for Repeated Applications of Load to Concrete Cylinders (side view).

Figs. 1 and 2, this was done by placing the proving levers at one end between the main levers, which were tied together at the other end by heavy rods, the whole having the appearance of a huge nut-cracker.

Clearance for the specimen limited the short arm of the lever to a minimum of about 10 ins. The space in which the machine was to be erected set a maximum limit on the length of the lever of about $6\frac{1}{2}$ ft. The preliminary computations were made on the assumption of 150,000 lbs. capacity, a main lever

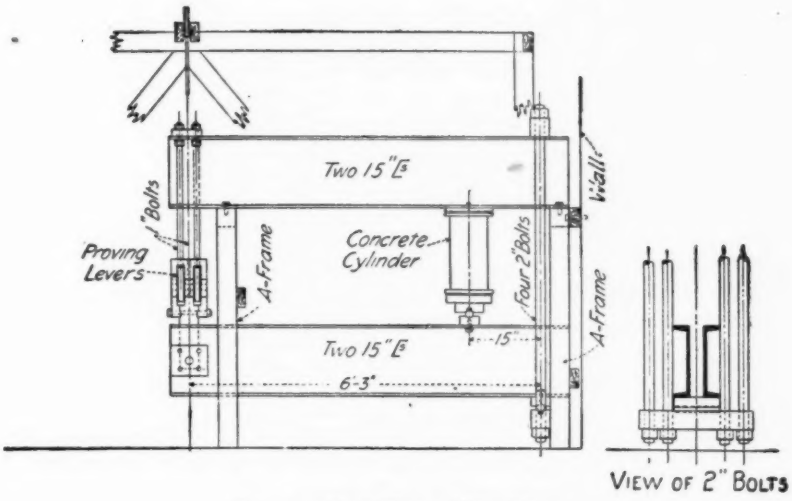


FIG. 2.—End View of Machine.

with arms of 75 and 10 ins., and a maximum motion at the end of the long lever of $\frac{3}{4}$ in. Careful computations of the bending deflections, and the effect of the elongations of the tie rods, and the probable effect of the compression in the concrete, caused some doubt as to whether the full load could be developed with the $\frac{3}{4}$-in. motion. When tried it was found that the deflections were about twice what the bending computations had indicated. This may be accounted for in part by the effect of the bending in the connecting parts, but it is also due to the effect of the shearing deflection, which is rather large in the short arm of the main lever. Measurements of the deformations in the webs of these beams

on lines inclined at 45° with the horizontal have shown 0.00025 unit elongation in one direction, and 0.00007 unit compression in the other.

The lever ratio was changed by making the short arm of the main lever 15 ins. long. This reduced the capacity of the machine to 90,000 lbs., which has been sufficient so far. With this lever ratio there has been no trouble in the operation of the machine. At a speed of 30 applications per minute there is not the least indication of impact in the loading.

As indicated on the drawing the main levers are made up of two 15-in. 33-lb. channels set 3 ins. apart. Only the lower one moves. It rests on a 1½-in. steel roller that bears on a hardened piece of tool steel, ground true and inserted in the 4 by 4-in. soft steel yoke across the bottom. A similar roller and hardened steel bearing are used beneath the specimen. Rollers instead of knife edges were used because of the motion and the high unit pressures, which it was thought would soon destroy an edge. The rollers have failed to show the least sign of wear on the hardened surfaces from about 300,000 applications of loads, causing a pressure of about 6,000 lbs. per linear inch, although they have embedded themselves perceptibly in the soft steel of the bearing attached to the lever.

Spherical compression blocks are used at each end of the specimen. It is set in plaster of Paris, which is allowed to harden under slight pressure before the loading is begun. Several specimens at failure have cracked all round and spread in all directions in a manner indicating very uniform application of stress. The readings of the deformations, as taken at three points in the circumference, also indicate truly axial loading.

In beginning a test the first load is applied by increments up to the stress to be repeated and the deformations measured to the nearest 0.0001 in., so that a regular stress-deformation curve may be plotted. Thereafter the readings of deformations are taken only with the load on and load off. These readings are made frequently at the beginning of a test, after about 100, 500, 1,000 and 5,000 repetitions. Then they are taken only at intervals of about 10,000 applications. For loads less than 60 per cent. of the ultimate strength, they need be taken only as often as about 40,000 applications.

The deformations are measured with a special strain gage developed and made in the shop of the Civil Engineering Department. Instead of being permanently attached to the specimen, where it might be injured by an unexpected failure, it is held in the hand and applied to the gage points. It consists of a frame with a fixed conical steel point at one end, and a bell crank lever with a similar steel point at the other end. The motion of the

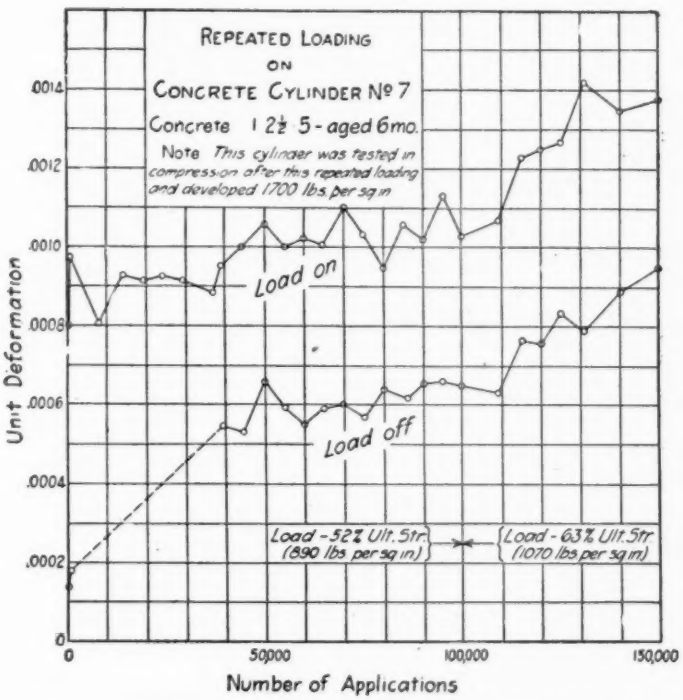


FIG. 3.—Typical Curves showing Effect of Repeated Loads

long arm of the lever as the distance between the points changes is measured with a micrometer. The gage points may consist of small pieces of steel rod attached to the concrete by plaster, though a special gage point has been arranged fastened to the specimen by a wire and touching it at three points, one of which is a steel ball free to roll in a guide, the other two being in a line at the end of the gage length under measurement. By this

device there is no uncertainty as to the length of the concrete from which the measured deformation arises.

Readings are taken to the nearest one ten-thousandth of an inch. A record is taken of the temperature of the room and of the reading on the standard gage with which all the readings are compared. In the reduction of these readings any temperature variation may be corrected.

A plot of the data taken from one specimen is shown in Fig. 3. The cylinder was loaded to slightly over one-half the average ultimate strength of five specimens made from the same batch of concrete. Readings were made on a 6-in. gage length at intervals of about 5,000 applications. As shown on the diagram the first few applications made a unit set of about 0.00015 and the first 50,000 applications about 0.00055. This was increased to about 0.00065 by the second 50,000 applications.

After 100,000 applications of 52 per cent. of the ultimate strength, the load was increased to 1,070 lbs. per sq. in., or 63 per cent. of the average ultimate strength. About 50,000 applications of this load increased the unit set from about 0.00065 to 0.00095, almost 50 per cent. The specimen was then taken from the machine and tested in the usual manner for its ultimate strength. It developed 1,700 lbs. per sq. in., which was slightly higher than the average of the five specimens tested without repetition for the "100 per cent." strength; so we can not say that the 150,000 applications of loads greater than are allowed in practice, 50,000 of which were more than 60 per cent. of the ultimate strength of the material, had any harmful effect on the strength of this cylinder. But the slope of the line showing the increase in the set would indicate that some action resulted from the repetition of the load; to determine what may be the real significance of this action, is one of the purposes of the investigation.

DISCUSSION.

Mr. Schuyler.

MR. MONT SCHUYLER.—I should like to ask Mr. Berry how many repetitions per minute his apparatus accomplished.

Mr. Berry.

MR. H. C. BERRY.—Our brick rattler runs 30 revolutions per minute. By careful adjustment of the pawls at the end of the levers the loads may be so applied as to avoid any impact effect. By use of a water rheostat the speed may be reduced to 14 revolutions per minute, but the effect of changes in the rate of application has not been investigated.

Mr. Schuyler.

MR. SCHUYLER.—As I recall it, less than four applications of the load per minute were attained in the laboratory of Washington University, where the first work of this character on concrete was done. In the Laboratory of the City of St. Louis we found a great difference in the strength of identically fabricated cylinders when tested at the slowest mechanical speed and when the crushing head was run down by hand. For instance, at the slowest mechanical speed, $\frac{1}{4}$ in. per minute, specimens would develop 60 to 70 per cent. more strength than similar specimens that were tested with the machine manually operated at such speed that micrometer readings could be taken after the beam had floated stationary for about a minute without further motion of the crushing head. I think that perhaps the high rate of repetition adopted in the work here described may have been the cause of the extreme powers of endurance exhibited.

Mr. Howard.

MR. J. E. HOWARD.—The effect of repetitive loading on mortar is somewhat different from that on neat cement. A fairly uniform modulus of elasticity pertains to the cement, and stresses can be applied to neat cement a number of times without apparent injury, or change in the value of the modulus. With mortars, however, sets are developed and an apparent change in the modulus of elasticity takes place. This is thought to result from the disintegration of a portion of the material and the consequent increase in the intensity of the stresses on the undestroyed portions. If this view is correct, it materially aids in understanding the phenomena which are observed.

AN AUTOGRAPHIC RUBBER-TESTING MACHINE.

By Thorsten Y. Olsen.

Rubber has in the past few years been subjected to tests by the United States Government and possibly by a few large users, such as railroads, etc., but it is now passing beyond this stage and the rubber manufacturers are devising more thorough tests to determine the quality of their product. At the meeting of the International Association for Testing Materials last year, the question of rubber testing and machines for that purpose was considered, showing a universal tendency toward more complete methods for testing this material.

The machine here described was designed at the request of Mr. H. C. Geer, Chief Chemist of the B. F. Goodrich Rubber Company, in order to obtain more complete data and to determine various characteristics of rubber not obtainable on any present testing machine. This machine is shown in Fig. 1. It may be used for simple tension tests, for tests under repeated loads, and for tests under a constant load, and will make an autographic record in each case.

General Dimensions.—The machine is designed to test a strip of rubber about $\frac{1}{8}$ in. thick, 1 in. wide and 6 ins. long, which is reduced in the center to a width of $\frac{1}{2}$ in. for a straight length of 2 ins., on which length the stretch is measured. The specimen may be stretched twenty times its original length, allowing for the large amount of stretch which takes place in the heads of the specimen. This length, together with the weighing and straining mechanism, makes the machine as shown 9 ft. long.

Method of Weighing the Load.—The pendulum-balance method was selected as the most accurate automatic means of weighing the load. It was found essential that the load should always be on the specimen, inasmuch as an autographic record was desired of both the application and the removal of the load. This excluded any lever device. A spring balance would in no case be accepted, so the pendulum balance was the only available means left for the purpose.

The pendulum used in this machine is somewhat on the same

principle as that in a pendulum machine I described before the Society two years ago, in that the force of gravity acting on the pendulum is overcome by the large weight shown at the left end of the machine. By this means, a pendulum of half the weight which would otherwise be used, can be moved twice as far to produce a certain amount of work, and the large scale so obtained is one of the features of the machine. The weight is connected to one end of the pendulum and the carriage gripping the rubber to the other end, so as a whole it is a balanced system. A set pointer is carried around by the pendulum, which will remain in the position occupied at the point of rupture of the specimen. A rack is placed underneath the machine, into which a series of palls fall as the test proceeds, holding the weight on rupture of the specimen and thus saving it from injury. These palls are controlled by the small hand wheel shown on the pendulum. The scale reads by half-pounds up to a maximum capacity of 200 lbs.

Straining Mechanism.—The straining mechanism consists of a screw running the entire length of the frame and operated through a series of gears and a four-to-one variable-speed motor, so that testing speeds of from 6 to 24 ins. per minute may be obtained by motor control. The screw operates the straining head, which is guided in the machine and can be disconnected from the screw by a hand wheel and thus quickly set by hand where desired. The motion of the screw is controlled by the hand lever projecting at the back of the machine.

Repeated Load Mechanism.—This apparatus is designed so as to apply a reciprocating motion to the straining head, in which case the head is disconnected from the screw. The length of the stroke may be varied, and any desired load may be applied. The motion is transmitted to the straining head by a crank and is controlled by the hand lever shown to the right of the machine.

Straining under Free Load.—In this case also, the straining head is disconnected from the screw and weights of any desired amount are suspended from the extreme right end of the machine and the effect noted in a given time.

Method of Gripping Specimen.—The specimen is held between two rollers which are operated simultaneously in each head by hand levers, in such a manner that the greater the pull the tighter they squeeze on the rubber. The rollers operate over the wedge-

shaped sides of the head in a manner similar to that in which the wedges in any of the larger Universal iron- and steel-testing machines operate.

Autographic Device to Record Tension Tests.—The autographic device is one of the most difficult parts of a testing machine to design properly—especially in a rubber-testing machine. The deformation in a test of this kind must be greatly reduced to take in an elongation of twenty times the original gage length,

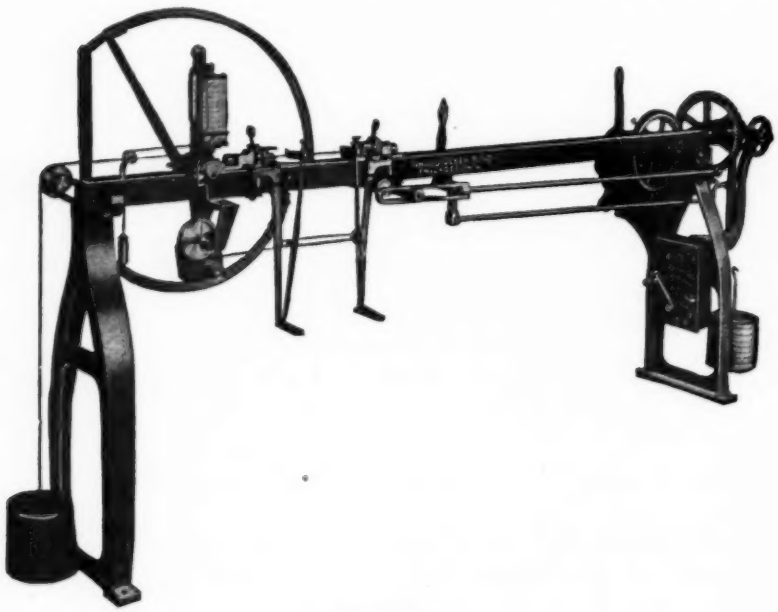


FIG. 1.

and a height of 5 ins. was determined as the most convenient to represent the elongation on the diagram, with a length of 10 ins. to represent the load of 200 lbs.

The movement of the pendulum is transmitted so as to rotate the drum, a motion of the surface of the drum of $\frac{1}{2}$ in. representing 10 lbs. pull on the specimen. The weight indicated by the pendulum varies with the sine of the angle, and this was considered in the design and the error eliminated by the method used in transmitting the motion to the drum.

The elongation between two clamps placed on the specimen is measured by means of the two long levers shown. These levers are so related to each other and connected to the recording pencil, that only actual elongations between the clamps are noted on the diagram. The stretch of the specimen can be so recorded that the width of the card of 5 ins. will represent either 10, 20, or 40 ins. of deformation, and this change of ratio can be made in less than a minute. The stretch between the clamps and the heads, and the stretching of the specimen in the heads, is so large that provision was made to take care of 7 ins. of such stretch in each head. The finger arms fit in grooves in the clamps and are free to move up or down with the motion of the long levers, and are thus always in contact with the grooves of the clamps. The apparatus can in no way be injured by the breaking of the specimen, and the finger arms are thrown aside and out of the way if struck by the flying rubber or clamps.

This autographic device will thus record the characteristics of the rubber under application and removal of the load and the amount of set due to stretching the specimen under any load may thereby be determined.

Autographic Time Tests under Free Load.—The load is applied in this case by weights, as already mentioned. The connection between the pendulum and the recording drum is removed, and the drum is operated through gearing by the small weight hanging to the left of the machine and controlled by the clock shown above the weight, in such a manner that the drum rotates once in $2\frac{1}{2}$ hours. The clamps and finger arms are applied as in taking regular autographic tests, and a curve is obtained with the stretch as ordinates and time as abscissas.

Autographic Repeated-Load Tests.—Repeated-load tests may be made as described above, and recorded in the same way as for tensile tests. The line formed by the combined records of the various loadings will give the characteristic for the test.

In conclusion, I may say that this machine was to be designed only for autographic tensile tests, but since it was realized that in the future autographic time tests as well as repeated-load tests would be required, the machine was designed to cover these and was thus made a universal autographic rubber-testing machine.

A NEW MACHINE FOR TESTING PITCH.

By Thorsten Y. Olsen.

Pitch, as we all know, is one of the best binders that can be used in road construction. Its great value is due largely to its adhesive quality, and for this reason a new method of testing for this quality was devised by Mr. Fulweiler, of the United Gas Improvement Company. At his request, the writer designed a new type of impact tension-testing machine which will subject all samples of pitch to the same conditions, and will provide a test which can be duplicated at any time on any machine built on the same principle.

The method of testing the pitch consists of determining the amount of energy required to force apart two specially designed dies held together by the pitch. To make this method a success, two important factors must be considered: First, the size and form of the dies; second, the method of applying and measuring the energy.

The first factor was carefully determined by Mr. Fulweiler, after numerous experiments. The standard dies are 1.1 ins. in diameter. Three concentric grooves are turned in one die, and into these, projections on the other die fit in such a manner that when pressed together, a thin filament of pitch will be left on all sides of the concentric grooves. The grooves are so prepared that the pitch is forced out from the center, thus filling all the grooves uniformly. The shape of the die was determined by experiment until it reached such a form that any further change, altering the thickness of the pitch filament, would decrease the amount of energy required to force the dies apart.

As pitch has a certain viscosity, varying considerably with the various grades and with the temperature, etc., it is essential that it be tested always under the same conditions; and owing to this viscosity it is essential that no time factor shall enter into the method of testing. To force the dies apart, it is therefore necessary to apply tension by impact.

The machine designed for this purpose is shown in Fig. 1. It consists of a weighted pendulum which is dropped from a certain height, striking a crank lever, which in turn forces the dies apart. The crank lever was used as the only medium by which the force of impact can be transmitted to the dies, and which will at the same time allow the pendulum to continue its course and thus provide a means whereby the energy used in parting the dies can be measured.

This energy is read directly off the scale, which is so gradu-

FIG. 1.

ated that no correction need be made for the energy utilized in operating the crank lever or in moving the pointer.

The pendulum is held in place at the beginning of its stroke, and released by a latch shown in the illustration.

The lower die may by a quarter turn be gripped firmly in the frame of the machine; the upper one is placed in a yoke swung from the crank lever at the top and guided by the frame at the lower end so as to ensure a direct straight pull on the pitch.

So far, but few tests have been made on this machine, for it has just been completed. Being a new type of machine, it has

taken more time than was expected to perfect it, but as the principle involved is correct, there is little doubt but that it will form an excellent machine for its purpose.

A machine of this type can be arranged to make impact tension tests of standard cement briquettes, which may give some interesting data on cement. A machine of larger capacity built on this principle, with the proper gripping device, would form an ideal machine for impact tension tests of metals or for testing small nicked bars over a die in determining the fragility of steel.

DISCUSSION.

MR. W. H. FULWEILER.—I have probably had more experience with this machine than Mr. Olsen, as it was built for us. We have been working for some time to get what we thought would be the binding value of road materials. There are many kinds of material used in road construction, and it seemed to us that their primary object, particularly as applied in macadam construction, is to resist the horizontal shear impressed upon the road by motor vehicles. This shear is applied very rapidly. For the ordinary touring car traveling thirty miles an hour, the stress rises from zero to a maximum in about 0.0065 second. We tried the instantaneous application of the load as more nearly approximating the conditions under which the material is used, and we consider this instantaneous application of more importance than the question of the form of die. We first tried a number of dies with flat faces, but we found that these had apparently more or less of a vacuum effect. They did not seem to give accurate results. Then we tried a single die—a male and female cone, copied from one used in the Office of Public Roads, at Washington; and we found that by employing a number of concentric grooves we got very concordant results. The die is made so that the male wedges have a slightly greater angle than the female wedges, and the two dies when filled with the pitch are forced together in a specially designed clamp that provides a true rectilinear motion, so that the dies meet at a center point. The surplus pitch that is pressed to the outside through the small clearance is wiped off, and the dies are put in water at a definite temperature. Then they are taken out of the water, immediately put in the machine, and broken. This takes only about 30 seconds, so there is no chance for any considerable change in the temperature of the material. The actual size or design of the die was determined by experiment. The first die gave rather poor results. Then we gradually changed the angles and also the clearance, which is the most important feature. As the clearance is gradually increased the value rises, but on continuing the increase it begins to fall again. We have

Mr. Fulweiler.

Mr. Fulweiler. made a number of tests in that way with different clearances, and we have finally found one that gives the maximum value. One kind of material was used to a great extent in determining this maximum value. It may develop that a clearance which is satisfactory for a water-gas or coal-gas tar pitch is not satisfactory for asphalt. We have not as yet had time to work that out, but we will do so eventually.

Another important feature of the machine is the fact that it is adapted to testing a large range of materials, from liquid road oils or very liquid tars, to absolutely solid native asphalt. The form of the die is such that it retains the material tested. We have made only a few tests with the particular machine that was described, but another form of the machine, which has the same die and which applies the impact load, we have been using regularly in our routine work for the past two years. I will give you, briefly, some idea of the values obtained, which are of course relative. For instance, in some residual oils we find values running from 1 to 17 lbs.; in some blown oils we find values running from 9 to 132 lbs.; in some tars the range is from 26 to 225 lbs.; in natural bitumen, from 65 to 151 lbs.; while in some mixtures of oils, tars, asphalts, natural bitumens and fluxes, it is from 1 to 200 lbs. The striking feature of the tests is that the viscosities do not have any relation to the strength. Thus, there are some materials that are very viscous and heavy, which the uninitiated might regard as very strong binders; yet when tested in this machine they show almost no binding strength at all. We had hoped to report a large number of tests, but the machine was not finished in time to make that possible.

Just what this machine shows is, I think, decidedly questionable. We have called it an impact binding-strength machine for lack of a better term. I am quite sure that it is not a measure of viscosity; and I am also sure that it is not a measure of adhesion, because when the dies are broken the material extends up and down in long hair-like streamers, very much in the shape of the fracture that Mr. Abraham showed us as occurring in asphalt materials. If the material does not adhere to the die, we consider that the test is not a good one, and we repeat it a number of times at higher temperatures. If it then fails to adhere we conclude that the cohesive strength of the material is considerably greater than

its adhesive strength, and that it is probably not well adapted to road work. **Mr. Fulweiler.**

MR. MONT SCHUYLER.—Am I correct in understanding that the material is placed at the center of the dies and forced outwards by pressing the two dies together? **Mr. Schuyler.**

MR. FULWEILER.—In handling the heavier material, both the dies and the material are heated so that it readily softens. Of course, the temperature varies with the different materials. In testing a liquid material, we do not heat either the die or the material; but in testing the heavier pitches, particularly the natural asphalts, we have to heat both to secure adhesion. Both dies are then filled and the excess is pressed out. **Mr. Fulweiler.**

MR. SCHUYLER.—I did not refer so much to the manner in which the material is applied as to the fact that the two parts are forced together until metal meets metal. This means that as the material cools, internal stresses are developed. Therefore the temperature of application and the coefficient of expansion of the material under test might lead to falsely varying indications for materials of equal merit, or vice versa. I object to the apparatus only on account of the form of the die. **Mr. Schuyler.**

MR. FULWEILER.—I do not know whether the paper should have been presented at this time, as there seem to be a great many theoretical objections to the machine; but during two years of practical work, involving tests of from eighty to a hundred samples of different materials, the results obtained with the machine checked up very well with the results found in practical experience. Therefore, so far as our work has gone,—and we have checked it over the entire range of materials that are in use in road building,—we find it a very valuable asset in giving us a line on the characteristics of material. The objection just made may be a valid one, but from the fact that the materials are not solids at the temperatures at which they are tested, and from the design of the dies, we do not believe that there is any possibility that internal stresses will affect the tests. **Mr. Fulweiler.**

MR. A. S. CUSHMAN.—Nearly all the materials that we use for road-building purposes flow to some extent at ordinary temperatures. If the material had to be liquefied in any way and then on cooling down turned to a solid-like grahamite or gilsonite, then the objection in regard to internal stress might be valid; but **Mr. Cushman.**

Mr. Cushman. I cannot think that in simply changing from a less to a slightly more viscous substance, any internal stresses are going to interfere with the value of the test. What I do anticipate will interfere with the value of the test is the suction effect. I do not think that the form of dies as first used in the Office of Public Roads and afterwards modified by Mr. Fulweiler, have quite gotten over the difficulty. In any such test, the important point is that the results shall be in accord with those obtained in service. Whether this will prove to be the case remains to be seen.

Mr. Schuyler. MR. SCHUYLER.—Under road conditions the effects of impact are seldom felt except under a rather high natural temperature which tends to relieve the internal stresses. If the dies here described were so constructed that they could be brought to within a certain fixed distance of each other, held until hardening has taken place, and then allowed to approach until internal stresses have been relieved, their form would be improved.

Mr. Sommer. MR. ALBERT SOMMER.—On how many materials was this machine tried, and what differences were found in tests of the same material?

Mr. Fulweiler. MR. FULWEILER.—When one is accustomed to handling the machine, and is careful about the temperatures, the error for successive readings seems to be a fairly constant quantity, ranging from 3 to 5 lbs. We may get a maximum variation of between 0 and 5 lbs. on the lower readings, and for the higher readings at about 200 lbs., we get nearly the same variation. In other words, there seems to be some constant in the operation of the apparatus that is not affected by the load. I do not know just how to explain it; probably further study will rectify that.

Mr. Sommer. MR. SOMMER.—Have materials of greatly varying consistency been tested in this machine?

Mr. Fulweiler. MR. FULWEILER.—Materials have been tested in this machine that would readily pour out of a beaker and other materials that had a penetration of 32. In general, the softer materials gave lower values, which is to be expected, but this holds only for materials of similar composition and not for different classes of materials. We have had two samples with the same binding value, one having a penetration of 184 and the other 280. Again, we have had a sample with a penetration of 200 which showed only one or two points, while another sample of 320 penetration

gave 75 points. The usual lighter road oils give less than 20 points when they have a penetration higher than 350. **Mr. Fulweiler.**

MR. J. W. HOWARD.—This apparatus measures ductility under shock; therefore these softer materials, which are quite viscous under shock, will hold their tenacity a little longer than the stiff materials which break quickly under shock. In road construction we speak of a binder as being adhesive and having good binding qualities, but as yet there is no machine, either in Europe or America, on which direct physical adhesion or binding tests can be made. Such a machine is a desideratum, and many are endeavoring to devise one. The machine here described is not yet perfected, as has been indicated, but it may lead to something better. **Mr. Howard.**

MR. SOMMER.—In our laboratory we have devised a machine on which are used plates made from various materials, and on which we make tests similar to those made on this machine. We have not published anything about this apparatus because we found that each kind of material of equal consistency, regardless of origin, gave similar results, whereas when the consistency changed considerably, the tensile strength changed. I therefore came to the conclusion that the values for tensile strength in all machines of that kind are a function of the consistency of the material. I should like to ask whether the speaker has had a like experience. **Mr. Sommer.**

MR. FULWEILER.—No, we have not; that is the reason why we think this method differentiates between viscosity and binding strength. As soon as we found it did that, we continued our work with the machine. If the viscosities and the strengths had always run parallel, we would not have felt that we had gained anything; but when we found that the machine differentiated between materials of the same viscosities and different binding strengths, we thought we were getting indications of some value. **Mr. Fulweiler.**

MR. G. C. WARNER.—In regard to ductility under shock, since the advent of the automobile there is a double shock on the roads: first, the horizontal shear, and second, the suction that is immediately formed by the rubber. We certainly have suction as well as horizontal shear. **Mr. Warner.**

MR. CUSHMAN.—The suction of wheels of automobiles does not do much damage. Careful tests have shown that with automobiles traveling at high rates of speed the principal damage is **Mr. Cushman.**

Mr. Cushman. done by the driving wheels. Inspection of photographs of moving automobiles will show that there is a great difference in the pick-up and abrasion of the road surface between the rear wheels that are doing the driving and the front wheels, although all are revolving at the same speed and carrying the same load. It is the shear and slip of the driving wheels that picks up and loosens the road surface.

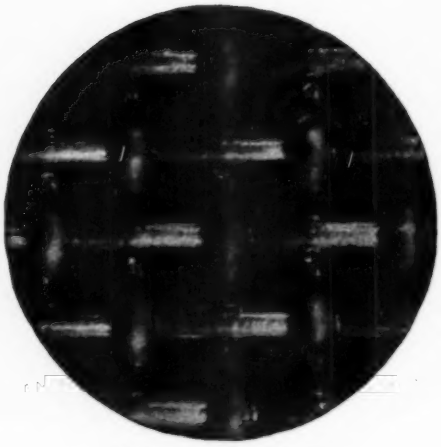
THE CLASSIFICATION OF FINE PARTICLES ACCORDING TO SIZE.

By G. W. Thompson.

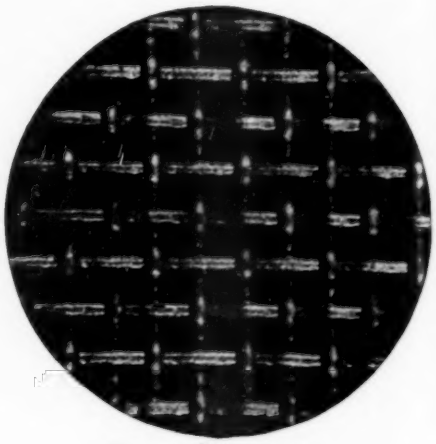
The classification of coarse materials according to size is very readily accomplished by means of screens. There are, however, many fine materials—pigments, cements, etc.—a large proportion of which will pass through the finest screens obtainable. Fig. 1 shows photomicrographs of No. 100 and No. 200 wire screens such as are used for cements, and of No. 21 silk bolting cloth, all of which are magnified approximately forty-five diameters. (All the photomicrographs shown in this paper have this same magnification.) It will be observed that the openings in the silk bolting cloth are smaller than those in the No. 200 wire cloth. Most pigments contain but a very small portion which will be retained on No. 21 silk cloth, and yet they vary considerably in degree of fineness—that is, in the proportion of relatively coarse and relatively fine particles. This is evidenced by the touch, by variations in tinting and oil-taking power, and by the voids in the dry pigments when subjected to uniform pressure, etc.

Students of paint problems especially have for a long time recognized the desirability of measuring the degree of fineness of pigments. There is no good definition at present covering fineness, and it would appear that much work must be done before this definition can be drawn up. The most important work in this direction is to classify the particles of a pigment, as far as practicable, into groups according to their size. We have constructed an apparatus (to be described later) which does this practically and effectively. This does not mean that the apparatus is not subject to limitations and that improvements cannot be made in the direction of making it more accurate and more useful for the purposes for which it was designed.

It is well known that homogeneous substances fall in liquids with a speed that varies with their size—that is to say, the larger particles fall more rapidly than the smaller ones; and if a stream of liquid can be given a definite upward flow, certain relatively



No. 100 Wire Screen.



No. 200 Wire Screen.

No. 21 Silk Bolting Cloth.

FIG. 1.—Photomicrographs (× 45)

coarse particles will settle out and other relatively fine particles will be floated away. Laboratory classifiers following this principle have been made for the classification of fine particles, but usually they have been built with the idea of making only two classifications. What we have attempted to do is to make five classifications with our apparatus in one operation.

Bodies fall with the same speed in a vacuum, without regard to their size or specific gravity. In fluids the fall is affected by the specific gravity of the substance and the surface it exposes. The greater the surface the greater the friction which retards the fall, and as small particles present larger surfaces in proportion to their weights than do large particles, large particles fall more rapidly. The surface decreases as the square, while the weight decreases as the cube of the diameter of the particles as they become smaller. It is probable that with a classifier working on spheres or cubes, very exact results could be obtained; but as particles vary from the spherical or cubical shape, the surface becomes greater and introduces other factors. This is one of the limitations of classification apparatus of this kind which must be fully recognized. But it appears probable that in the case of homogeneous substances the particles will vary regularly in surface according to their size, even if they are irregular in shape; that is to say, the very fine particles will be irregular equally, or approximately so, with the coarser particles and practical results will be obtained in their classification.

In a classifier depending upon the vertical flow of fluids, the velocity of flow corresponds (according to Callon's formulas, which are based on Stoke's studies) with particles of a certain size, specific gravity and shape; that is, at a given velocity such particles will just stay in suspension, and particles slightly larger, heavier, or with less surface, will sink.

There are other factors, however, than the size, shape and specific gravity of the particles which determine what this flow should be. They are the specific gravity of the fluid and the specific surface relation which this fluid bears to the particles in question. If we include in one general constant, C, the specific gravity of the liquid and the specific surface relation referred to, we can construct the following formula, which will give the velocity at which a given fluid should rise in order that particles of a certain size may just be kept in suspension.

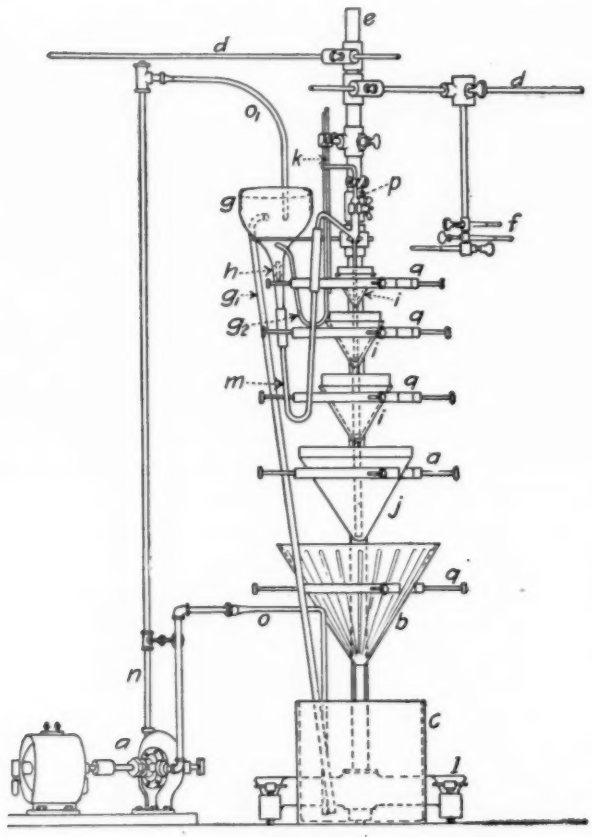


FIG. 2.

a, Centrifugal pump directly connected with a ⅛-h.p. electric motor; *b*, 13-in. ribbed glass funnel; *c*, 5-gallon glass aquarium jar; *d*, Steadying rods fastened to wall, 10 mm. diameter; *e*, General supporting rod, 1.6 meters long, 30 mm. diameter; *f*, Ring supports for funnels, used when cones are being cleaned; *g*, Special glass funnel with overflow; g_1, Glass tube to aquarium jar; g_2, Rubber connection to gage; *h*, Regulating tube, 50 mm. long, 2.5 mm. diameter, fitted in neck of funnel through cork; *i*, Cones set in funnels, supported on three lead wires, 1 mm. diameter, to allow for overflow from cone; *j*, Cone No. 4 without glass funnel; *k*, Millimeter gage showing head; *l*, Special tripod base; *m*, ½-in. block tin piping connected by rubber tubing; *n*, ½-in. brass piping with gate valve, connections, etc., from pump; *o*, ½-in. block tin piping from reservoir connecting with brass pipe; o_1, ½-in. block tin pipe; *p*, Special glass tee with stop-cock, for starting flow; *q*, Cast-iron rings with three threaded pointed bolts—supports for funnels and cones.

Let v =the velocity, C =the constant referred to, D =the specific gravity of the particle, d =the specific gravity of the fluid, and a = the linear dimension of the particle or its mean diameter.

Then:

$$v=C\sqrt{a(D-d)}$$

From this it is seen that the mean diameter of the particle is proportional to the square of the velocity; that is, if we double the velocity we quadruple the diameter of the particles left behind, etc.

The apparatus which we have designed is shown in detail in Fig. 2. It consists of four brass cones placed one above the other, arranged so that the overflow from the top cone, passing through a funnel, discharges into the bottom of the second cone, and the overflow from the second cone passes through a funnel into the bottom of the third cone, and so on.

The apparatus is arranged so that the liquid used can work at a constant head, which is indicated by a gage. We have found it most satisfactory for the purposes for which we have used this apparatus to use kerosene as the floating medium. This selection was made on account of the high wetting power of kerosene and its low viscosity. The apparatus was constructed at the start by guesswork, and we made our first cone with a base diameter of 75 mm., and as that apparatus was constructed we found that working under a 10-cm. head we got a vertical flow of 5 cm. in the top cone. The second cone was made to have a base area twice that of the first cone, the third cone to have twice that of the second, and the fourth cone to have twice that of the third; so that the fourth cone has one-eighth the speed of flow that the first cone has. Then, theoretically, the smallest particles caught in the fourth cone should have one sixty-fourth of the diameter of the smallest particles caught in the first cone, which holds good through the series. This, of course, is based on the supposition that the particles are spherical or cubical. We have no means of determining what this relation would be with particles varying appreciably from the sphere or cube.

The diameters of the four cones as finally decided upon were:

First cone	75	mm
Second cone	106	"
Third cone	150	"
Fourth cone	212	"

Some trouble was experienced in our early experiments in controling the flow. We used various devices, and found that the best method of control was by means of a small glass tube about 2.5 mm. bore and 50 mm. long.

The flow of liquids through tubes is based on the formula of falling bodies, the velocity of flow being proportional to the square

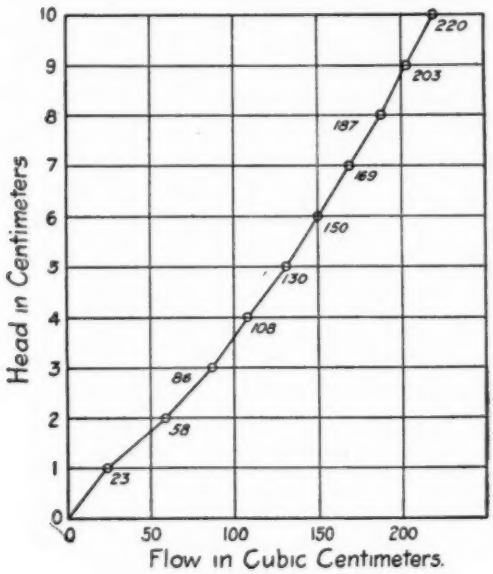


FIG. 3.—Flow Curve.

root of the height or head, except in so far as there is a loss by friction. The simplest way of expressing this formula is:

$$v = C_1\sqrt{h - h_1}$$

where v = the velocity, h = the head, h_1 = the loss of head due to friction, and C_1 = a constant including the size of tubing through which the flow takes place, gravity, etc. We can calculate C_1 algebraically by assuming that at any two points high in the rate of flow, C_1 and h_1 remain constant. Having done this we can calculate the variation in h_1. Ordinarily we find that above 5 cm., h_1 is constant; that is, the loss in head due to friction is uniform above a certain head.

After setting up the apparatus, leveling all its parts and making sure that all the parts are vertically above one another, in so far as is necessary, a flow curve similar to that shown in Fig. 3 is constructed, giving the flow in cubic centimeters for heads from one to ten centimeters. If, therefore, it is desired at any time to make a classification test operating at a different flow, this flow and the necessary head at which to work can be obtained from the flow sheet or calculated from the equations obtained.

The apparatus was originally designed for lead pigments, especially white lead, and we have found that the classification working with a 5-cm. upward flow in the first cone gave most satisfactory results, and we have usually worked on ten grams of material. In order to obtain satisfactory results we believe that the amount of material used should vary directly with the specific gravity, and that if with white lead ten grams are taken, then for a material having a specific gravity half that of white lead, five grams should be taken. Furthermore, the flow should vary with the specific gravity according to the formula given above and which we repeat here:

$$v = C\sqrt{a(D-d)}$$

or if we make C_2 to include C and $\sqrt{a}$,

$$v = C_2\sqrt{D-d}$$

Consequently, assuming that d is the same for all materials, as D, the specific gravity of the material, increases, the velocity, v, also should increase.

It is more convenient to consider the velocity in cubic centimeters of flow, and we have standardized our apparatus to run 220 cc. per minute at a head of 10 cm. (for a 5-cm. vertical flow this would really be 220.85 cc.)

Assuming for the time being that

$$\begin{aligned} v &= 220 \\ D &= 6.60 \\ d &= 0.83 \end{aligned}$$

then C_2 in the above equation would be approximately 94, and with any new material having a specific gravity of D_1, the formula would be:

$$v = 94\sqrt{D_1 - 0.83}.$$

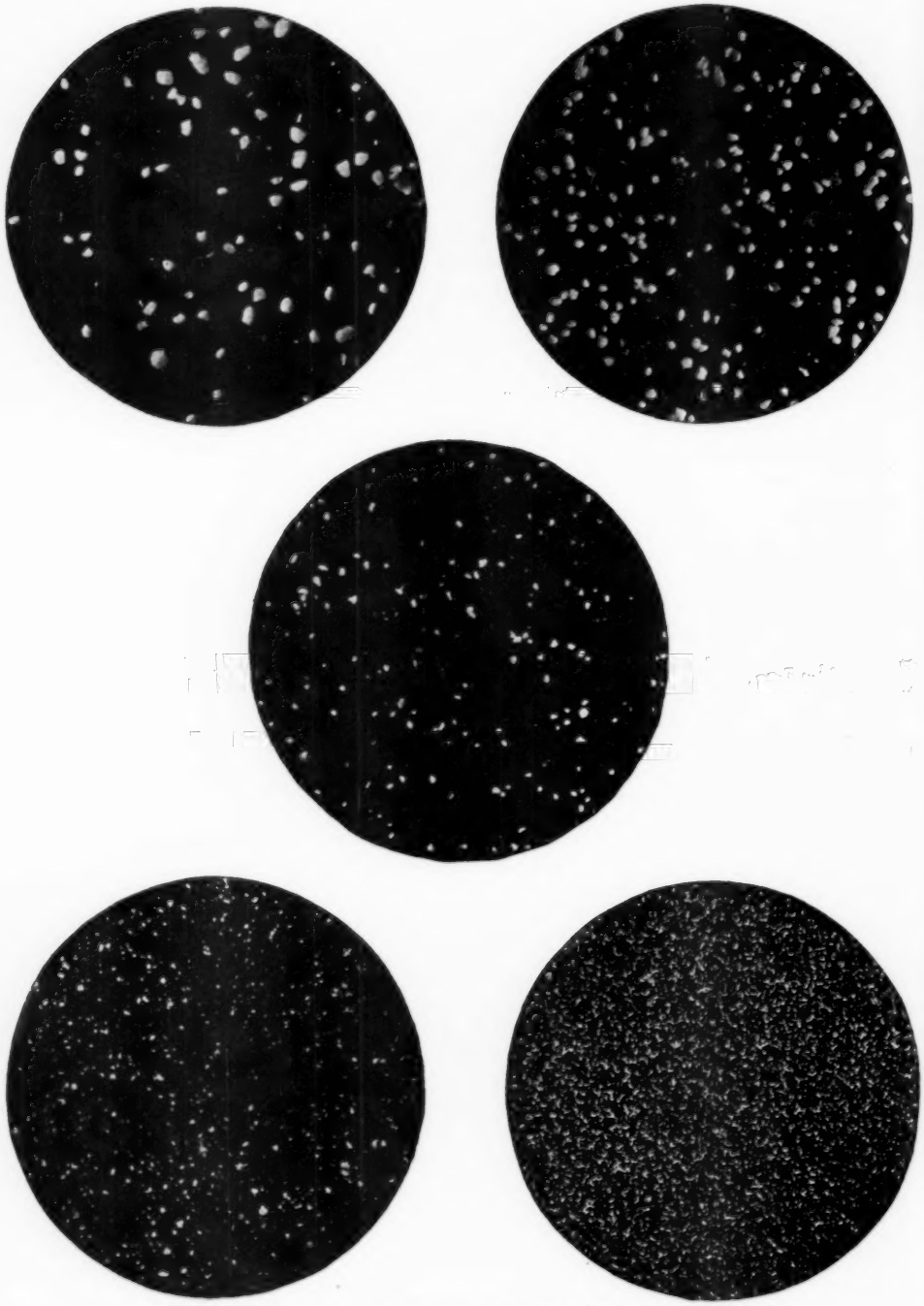


FIG. 4.—Photomicrographs of Classified White Lead (× 45).

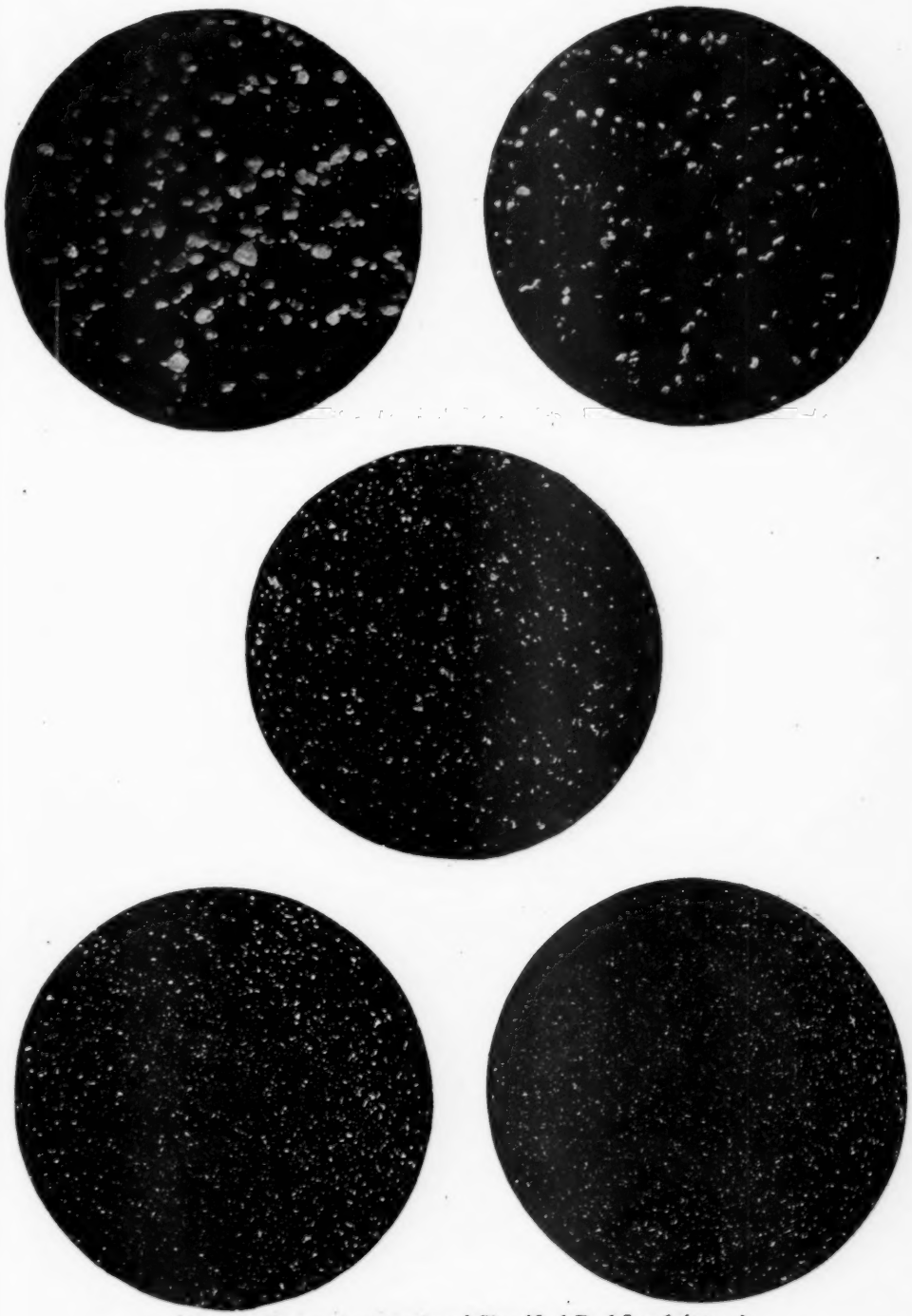


FIG. 5.—Photomicrographs of Classified Red Lead (× 45).

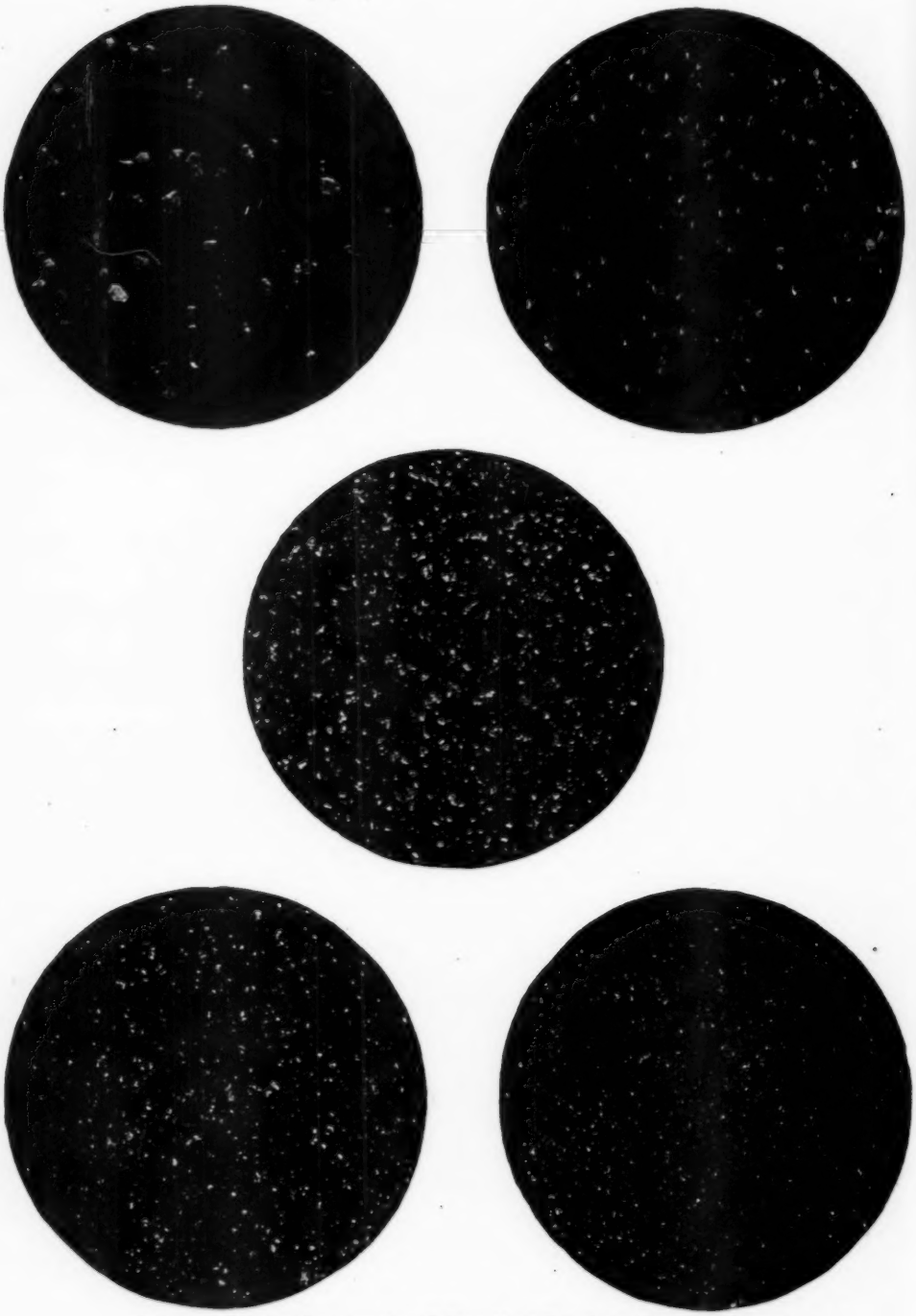


FIG. 6.—Photomicrographs of Classified Portland Cement (× 45).

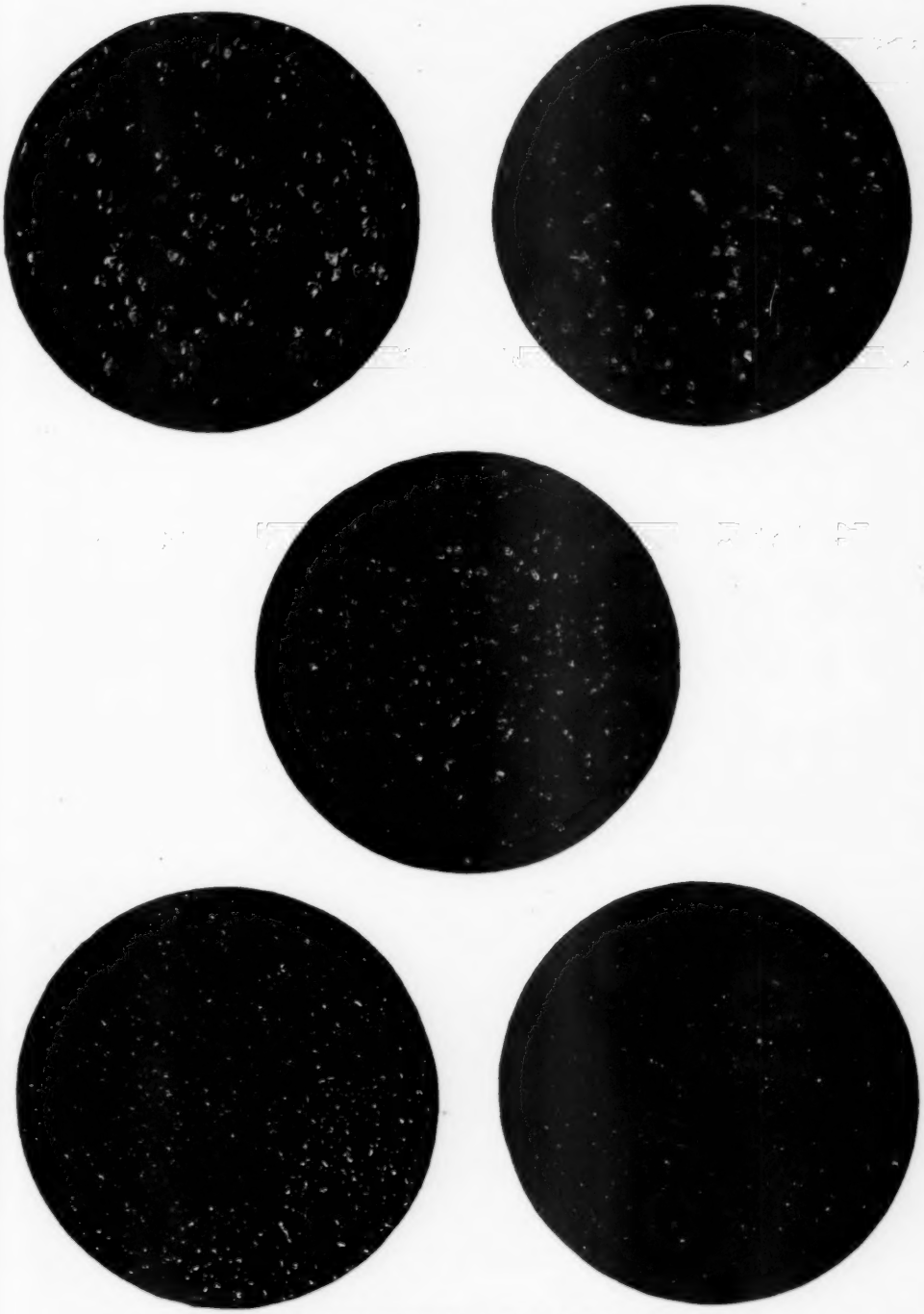


FIG. 7.—Photomicrographs of Classified Barytes (× 45).

If we were classifying a sample of barytes and found its specific gravity to be 4.3, the amount taken would be 6.5 grams and the flow would be:

$$v = 94 \sqrt{4.3 - 0.83} = 176.$$

The velocity 176 cc. per minute is only approximately reached by this method and it may be necessary to vary the head a millimeter or so to get the flow exact.

TABLE I. CLASSIFICATION TESTS.
All Values are Percentages.

Retained on	White Lead.	Red Lead.	Cement.		Barytes.		Ochre.
			No. 1.	No. 2.	No. 1.	No. 2.	
No. 21 silk cloth.	trace	trace	33.33	33.32	0.33	0.23	1.42
First cone.....	3.42	1.31	25.53	26.06	33.51	34.48	5.09
Second cone....	6.41	9.99	7.17	8.17	17.32	17.50	7.72
Third cone.....	6.61	14.98	8.05	6.29	16.16	17.69	10.79
Fourth cone....	8.72	28.70	6.82	7.37	9.69	9.15	12.95
Remainder.....	74.84	45.02	19.10	18.79	22.99	20.95	62.03

Table I gives the results obtained by the classification of four separate materials: white lead, red lead, Portland cement, and barytes. We have no serious difficulty in obtaining concordant results on white lead, red lead, and barytes. We have not done enough work on cements to be sure that the apparatus is applicable to them. It is our custom first to put the materials to be classified through No. 21 silk bolting cloth, and then to classify the particles that pass through this cloth.

Figs. 4 to 7, inclusive, are photomicrographs of classified particles of white lead, red lead, Portland cement, and barytes.

Fig. 8 shows a battery of three classifiers and an arrangement whereby two classifications are made using the first cone only.

It must not be assumed that the use of this classifier is simple and free from difficulties. It is probable that with every particular material which it is desired to classify, some special floating medium could advantageously and preferably be used. We have used kerosene because it seemed most available for our purposes. We notice, however, even with kerosene, that temperature affects the flow; that is, an apparatus standardized to deliver 220 cc. at a 10-cm. head at 60° F., will deliver a larger amount at 80° F.,

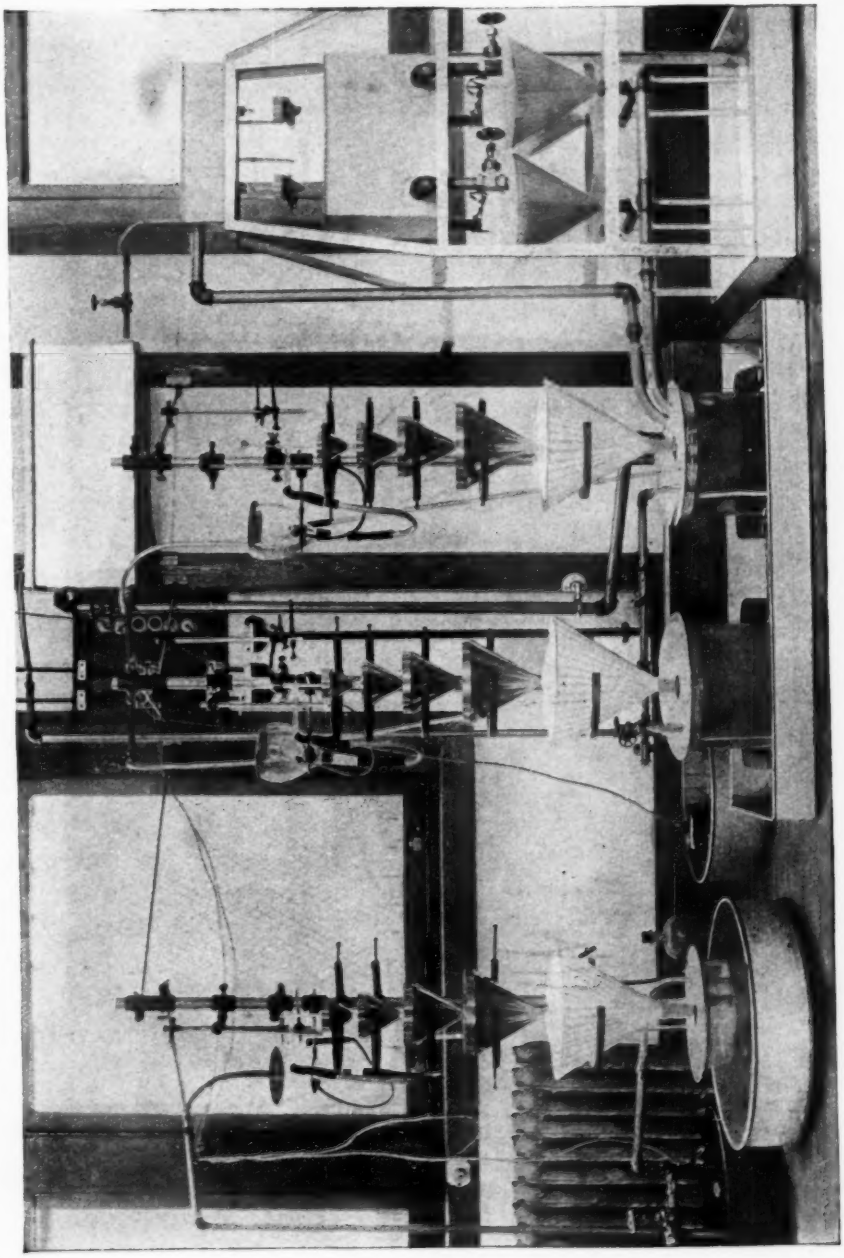


FIG. 8.—Battery of Classifiers.

the internal friction of the kerosene being less at the higher temperature and the kerosene also having expanded somewhat. It is probable, however, that this higher flow is accompanied by a lessened floating effect, so that the result will not be affected to the extent that the increase in flow would indicate. There is also at times a tendency of particles to flocculate which we have not entirely been able to avoid. This will, of course, cause fictitious results.

This classifier is operated as follows: The amount of the material to be treated is diffused in kerosene so that the particles are completely separated and transferred into the first cone. The glass tube is then lowered into the cone until it nearly touches the apex. The current of kerosene is then started, the level noted on the gage, and the air sucked out of the upper part of the glass T-tube. Ordinarily this is all one has to do until the classification is complete, which requires two hours. Sometimes the material to be classified settles in the first cone, in which case a slight tapping of the T-tube will start it in motion. When the classification is complete the kerosene is allowed to settle and is decanted. The sediment in each case is washed into clock glasses with kerosene, allowed to settle, decanted, and washed two or three times with ether. It is then dried and weighed.

DISCUSSION.

Mr. P. H. Walker.—I should like to ask Mr. Thompson what difficulties, if any, he experienced in collecting the small sub-divisions on a filter paper. I have noticed that pigments suspended in organic solvents are exceedingly difficult to catch on filter paper. I should like to know whether he got the last sub-division by filtering or by settling. **Mr. Walker.**

Mr. G. W. Thompson.—With the pigment material that I have worked on, I have had no trouble in filtering. I have used the C. & S. hardened paper. I have not worked on zinc oxides, because I assume there would be practically nothing caught in the cones; but with the material that I have worked on I have had no trouble at all from running through the filter. In nearly all my work I have used original pigments, not paints. Paints present a somewhat different situation, because many of them contain varnish, and such constituents are apt to give trouble. **Mr. Thompson.**

Mr. Walker.—You did not work on the pastes in oil, did you? **Mr. Walker.**

Mr. Thompson.—I have worked on white lead paste, and have had no trouble; but most of the other work has been on dry pigments. **Mr. Thompson.**

A COMPARISON OF MAGNETIC PERMEAMETERS.

By Charles W. Burrows.

Measurements of magnetic properties of materials are usually made on specimens in the form of comparatively short straight bars. This form is chosen because it is easily machined and readily inserted in fixed magnetizing coils. Neither of these conditions are met in the case of the ring specimen, although such a form is more desirable from purely magnetic considerations. For the testing of straight bars there are available several commercial instruments, besides a number of more strictly laboratory methods. Each piece of apparatus has its champions, who sometimes make extravagant claims and seldom, if ever, are willing to admit that an error as great as 5 per cent. exists in their particular type of apparatus.

In order to determine what agreement exists between magnetic data determined by different experimenters working with different apparatus, an investigation, of which this may be considered a preliminary report, has been undertaken. The method has been to measure in each apparatus the same specimen; or, if this is not feasible, specimens of as nearly as possible the same magnetic properties. This has been done with three different grades of material; a good quality of soft Norway iron, a medium quality of cold-rolled Bessemer steel, and annealed high-carbon tool steel.

Fig. 1 gives the normal induction data for these materials as well as for one sample each of nickel, silicon steel, and commercially pure ingot iron. From these curves one may get a general idea of the distinguishing features of the metals studied. These six rods were carefully measured by the author's compensated double-yoke method, and also by a certain Esterline permeameter. In Fig. 2 are plotted the corrections to be applied to values determined by the latter permeameter to bring those results into accord with my own.

These shearing curves show a characteristic course. For low and moderate inductions the correction is negative, that is,

the permeameter indicates a magnetizing force in excess of its true value. For the softer materials—iron, Bessemer steel and silicon steel—this initial correction is nearly proportional to the induction. As the upper inductions are reached, the shearing curve bends over toward the axis and passes through a point of zero correction. Beyond this point the correction changes sign and increases very rapidly. If this upper part of the shearing curve is plotted against H instead of B, it appears that in this region the correction

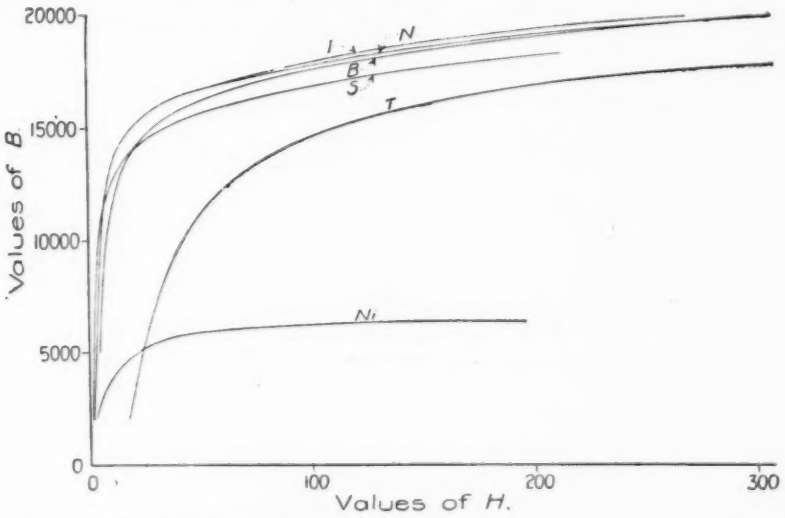


FIG. 1.—Showing Normal Induction Data for: Commercially Pure Ingot Iron (I); Norway Iron (N); Bessemer Steel (B); Silicon Steel (S); Tool Steel (T); Commercial Nickel (Ni).

approaches proportionality to H. This is also evident from the fact that in this region the shearing curves for the different materials lie relatively to each other in the order of their permeability.

In discussing results of this kind, one is at a loss how to proceed. We may consider the correction to be applied to H to reduce the observed value to the true value for a given fixed induction, or we may consider the correction to be applied to B to reduce the observed value to the true value for a given magnetizing field; or, lastly, we may employ a combination of the two. In discussing the results in this paper, I shall assume that the induc-

tion is fixed, and consider variations between true and observed values of the magnetizing field for each particular induction.

This is justified for two reasons. In the first place, the total induction across any section of a bar is a calculable function of the E. M. F. induced in a small test coil closely surrounding the rod, and hence the induction may be known exactly. On the other hand, the magnetizing force depends not only on the current and

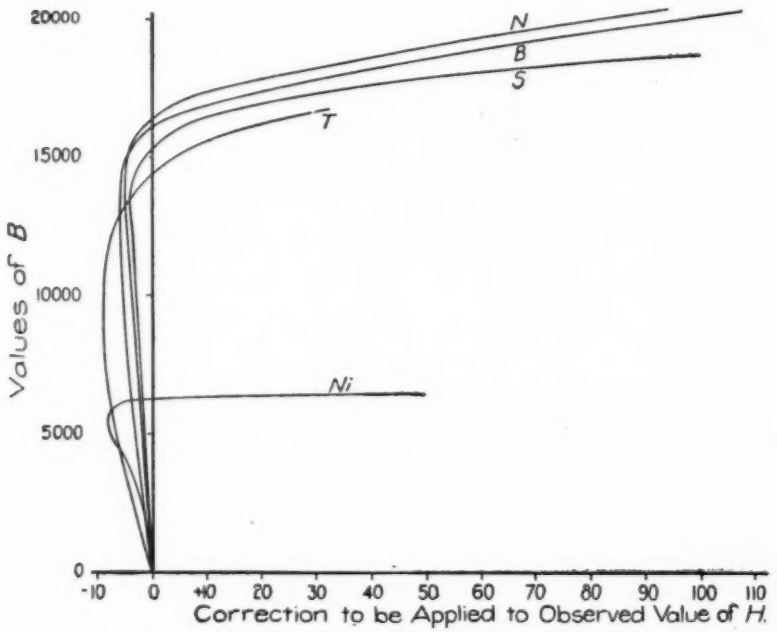


FIG. 2.—Showing Approximately the Corrections to be Applied to the Data for the Material of Fig. 1, as obtained from an Esterline Permeameter.

the winding of the magnetizing coil, but also in a complicated way upon all joints, gaps, and non-uniformities in the magnetic circuit. In the second place, most calculations of the magnetic portions of electrical machinery start with the assumption of a given flux density, and calculate the current-turns necessary to produce this flux. One must be warned, however, that as the lower inductions are produced by relatively small magnetizing fields, a small variation in the absolute value of this magnetizing field may appear

as a large percentage difference. This is evident from a comparison of Fig. 2 with Fig. 3, in which the data of Fig. 2 are represented as percentage variations.

Figures similar to Figs. 2 and 3 might be given for other forms of permeameter to show how the shearing curve depends on the instrument as well as on the nature of the test specimen. This has been done for the three materials, Norway iron, Bessemer steel, and annealed tool steel. It is not necessary, however, to present all the data, as a satisfactory comparison can be made by

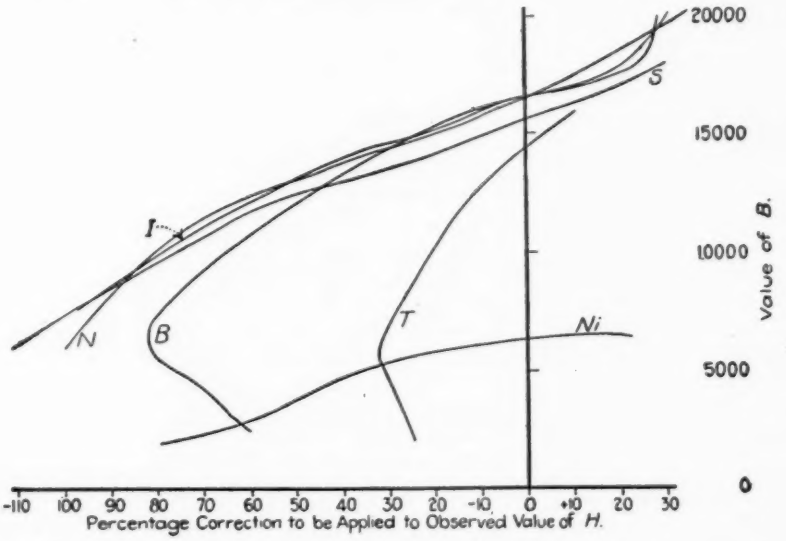


FIG. 3.—Showing the same Data as Fig. 2, in the Form of Percentages.

considering the shearing corrections for a single quality as tested in various permeameters.

Figs. 4 and 5 give the shearing curves and the percentage corrections respectively, showing the corrections to be applied to the data from different apparatus when testing a given quality of Norway iron. The same dentical specimen was not measured by each permeameter, but specimens from as nearly as possible the same stock were measured by an apparatus, and also by the author's compensated double-yoke method. The results are thus all connected by the data of this latter method, which for the

purpose of comparison were assumed as normal. The curves for an ovoid of dimensional ratio 100 are calculated from the theoretical value of the demagnetizing factor and the experimental data of the Norway iron of Fig. 1.

One can get a better understanding of these shearing curves by considering for a moment the individual corrections that are

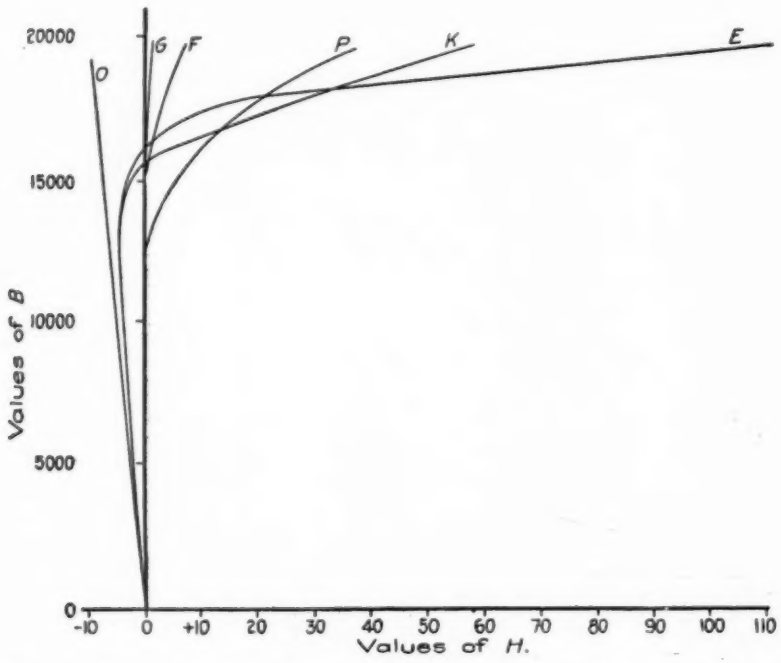


FIG. 4.—Showing Shearing Curves for a Given Quality of Norway Iron as Determined by Various Apparatus: *E*, Esterline; *P*, Picou; *K*, Koepsel; *G* and *F*, from Foreign Research Laboratories; *O*, a Theoretical Ovoid of 100 Diameters.

liable to enter into a magnetic measurement. Fig. 6 shows in conventional form a magnetic circuit consisting of the test specimen *T* and a yoke *Y* connecting the ends of the specimen. With modifications of details, this is the magnetic circuit of all types of permeameters. The magnetomotive force is applied through the solenoid *M* and the induction is measured by a test coil *t* surrounding the specimen, or by some other suitable device placed

in or near an opening in some part of the magnetic circuit. Whatever the individual arrangement may be, the corresponding corrections are modified in magnitude rather than in nature.

The greatest difficulty encountered is in the measurement of the field over the section whose induction is to be determined. At this section, *A* in Fig. 6, the field has at least two components, that due to the current in the solenoid and that due to the poles

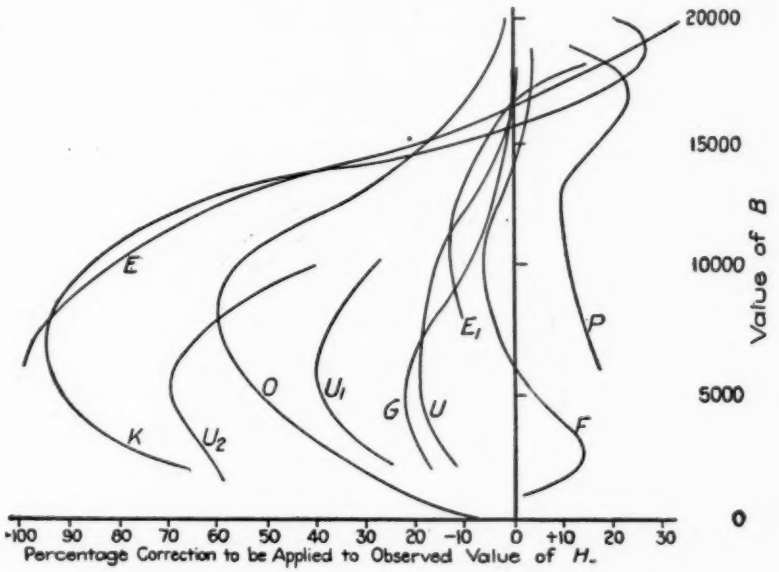


FIG. 5.—Showing the Data of Fig. 4 on a Percentage Basis.
E and E_1 are the extreme curves from four Esterline permeameters.
U is from an uncompensated double yoke.
U_1 is from a single yoke ($l = 27.8$ cm.).
U_2 is from a single yoke ($l = 16.8$ cm.).
O, *G*, *P*, *F*, are as in Fig. 4.

formed at the ends of the specimen where it joins the yoke. A third component is traceable to the fact that the yokes themselves are acted upon by the field of the solenoid. The field due to the poles at the end of the specimen is opposite to that of the solenoid, so that the true field is less than that indicated by the current in the solenoid. The magnitude of this correction can be calculated for a specimen in the form of an elongated ellipsoid without yokes.

Curve *a*, Fig. 7, gives the correction curve for such an ellipsoid having a dimensional ratio of 100. The field due to magnetization of the yokes by the solenoid is in the same direction as that of the solenoid. This correction will be proportional to the product of the current in the solenoid and the permeability of the yokes. As, however, the field in the region affected is comparatively small, and the permeability is small and slowly increasing, this correction will be nearly proportional to the current. The exact magnitude of this correction (Curve *b*) is difficult to calculate even approximately.

A correction to the observed induction is frequently necessary, due to the fact that the test coil, or the corresponding indicator, encloses some magnetic flux which does not pass through the

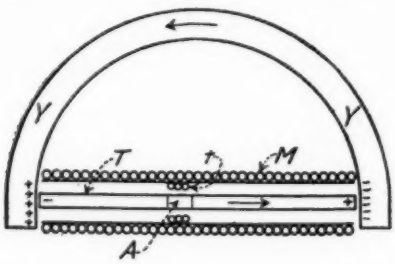


FIG. 6.—Showing a Conventional Representation of Magnetic Circuit.

specimens. Suppose, for instance, that the area of the test coil is four times that of the specimen. Since the field in the space immediately surrounding the rod is H, the test coil indicates an induction of $B+3H$. This is insignificant for low intensities, but becomes appreciable at the higher values. The corresponding correction to the magnetizing force in this case is easily seen to be $3H(dH/dB)$, where dH/dB depends upon the nature of the specimen. Curve *b* of Fig. 7 shows this correction curve for a particular bar of Norway iron. Curve *R* of the same figure is the resultant of Curves *a* and *b*, and shows a remarkable resemblance to the experimental curves of Fig. 2. In this resultant curve the lower portion is determined almost entirely by the demagnetizing action of the ends of the bar, while the upper portion is most influenced by the excess of flux measured by the test coil.

The shearing curves for the apparatus E and K (Fig. 4) are seen to be approximately equivalent to that given by an ellipsoid of 100 diameters when the induction is measured by a relatively large test coil. The Picou percentage correction (Fig. 5) seems to indicate an additional error proportional to H. This is quite probable, as with the short test piece used in this apparatus and the method of compensation of yoke reluctance it seems that the effective length assumed is too large. Such an assumption would account for over half of the measured shearing corrections.

Owing to the complex nature of the shearing correction, it is impossible to make a single fixed compensating device counteract the error at all flux densities.

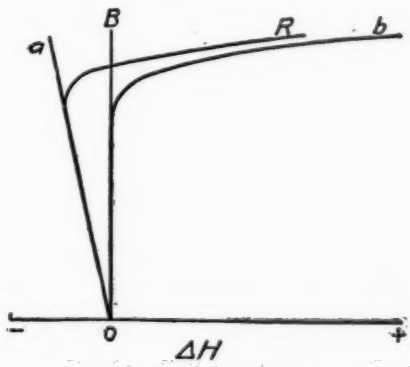


FIG. 7.—Showing Two Components of an Ideal Shearing Curve, and Their Resultant.

The Koepsel apparatus used for Curves K attempts to compensate for the field due to the action of the solenoid on the yokes by adding in series with the main coil a few turns about the yokes which oppose the main magnetomotive force. This accounts for the peculiar bending back of the shearing curve at high flux densities.

For the Esterline apparatus data were obtained from four laboratories, and Curves E and E_1 (Fig. 5) represent the two extremes in the shearing curves. The other two curves lie between these. Here an attempt is made to compensate for each source of error separately. The wide divergence between the two extremes E and E_1 seems to indicate that this adjustment is a matter of some uncertainty.

The Curves *G* and *F* of Figs. 4 and 5, which were obtained from certificates of two foreign research laboratories, and the Curve *P*, after the application of certain calculable corrections, show extreme variations of 5 per cent. at an induction of 20,000 gausses. This may be considered as a first approximation to the agreement that is attained by well-equipped laboratories. Direct-reading commercial instruments may be in error by as much as 100 per cent. of the true value.

In spite of the great differences which different methods give, it is encouraging to note that any one method applied consistently and carefully can be made to give results consistent within a few per cent. Consequently, by means of calibrated standard rods the correction curves can be drawn and the indications of one apparatus expressed in terms of another within 5 per cent.

THE EXPONENTIAL LAW OF ENDURANCE TESTS.

By O. H. Basquin.

Historical Note.—Forty years ago Wöhler published his pioneer researches on endurance tests.* His work is still unsurpassed in accuracy, in variety, and in adherence to method. The work of Wöhler, when compared with that of Spangenberg, is particularly interesting. Wöhler pointed out the principal facts now known regarding endurance tests; his conclusions were received with skepticism; Spangenberg undertook to repeat Wöhler's experiments, and, while his work, published four years later,† accorded entirely with Wöhler's conclusions, his results on no single set of specimens are as concordant as the most of those obtained by Wöhler. Twelve years later, in 1886, Bauschinger‡ attempted to show by his researches that his "natural elastic limit" for a material has the same value as that stress for which it will indefinitely sustain alternate loading.

After a further interval of fourteen years, in 1900, Ewing and Rosenhain§, by means of polished specimens examined under the microscope, were able to trace the history of a fracture under static load back to initial slips in the crystal grains; and in the same laboratory three years later Ewing and Humfrey applied the miscroscope method to an endurance specimen tested by rotation under cross-bending load. They found‖ the development of a fracture in endurance tests to accord completely with the early history of static breaks and they were able to detect early signs of ultimate fracture at stresses much below the elastic limit.

In the meantime Reynolds and Smith¶ extended Wöhler's conclusions to steel bars tested under direct tension and compression and at a rapid rate of alternation. The work of Stanton and Bairstow** published in 1906, while less concordant than that

* *Zeitschrift für Bauwesen*, 1870, p. 83, Berlin.
† *Zeitschrift für Bauwesen*, 1874, p. 485, Berlin.
‡ *Mittheilungen aus dem Mech. Tech. Laboratorium in München*, 1886.
§ *Phil. Trans. Royal Society of London*, A-Vol. 193, p. 353, 1900.
‖ *Phil. Trans. Royal Society of London*, A-Vol. 200, p. 241, 1903.
¶ *Phil. Trans. Royal Society of London*, A-Vol. 199, p. 265, 1902.
** *Proceedings Inst. of Civil Engrs.*, Vol. 166, p. 78, 1906.

of Reynolds and Smith, confirms their general conclusions; it extends the conclusions of Ewing and Humfrey to notched specimens tested for endurance under direct tension and compression, and it clearly points out the advisability of testing a material for endurance in approximately the form in which it is to be used in practice.

Stress-Repetition Curves.—Little attention seems to have been given to the possibility of finding a relation connecting the stress used in endurance tests with the number of repetitions required for rupture. Spangenberg, Reynolds and Smith, and Stanton and Bairstow have shown stress-repetition curves drawn to ordinary Cartesian coordinates. With decrease of stress these curves approach the axis of repetition and, finally, as the number of repetitions becomes very large, the curves become practically parallel to this axis. This means that the curves practically approach asymptotes parallel to the axis of repetition, and the ordinate of any asymptote is the stress for which the corresponding specimens will sustain a very large number of repetitions. Endurance testing has practically become a search for these asymptotes. It seems worth while to consider whether these curves really approach asymptotes or only appear to do so, and whether there may not be another method of looking at the problem that will be quite as satisfactory as the above, or even more so.

Logarithmic coordinates present a distinct advantage in the study of simple exponential curves, because these curves become straight lines for these coordinates and their equations may be written at once. Fig. 1 shows stress-repetition curves for nineteen sets of endurance tests, made by five different observers. The names of the experimenters, the kind of test, and the material, are given in Table I.

On the straight line marked A, the upper circle represents an endurance test by Wöhler upon a wrought-iron bar which was bent to one side and then released, the maximum stress due to bending reaching 53,500 lbs. per sq. in. This process of loading and unloading was repeated 169,750 times and then the specimen broke. This small circle on Fig. 1 is located in such a position that its horizontal abscissa represents the logarithm of 169,750, while its vertical ordinate represents the logarithm of 53,500. Four other tests with bars of the same material were made in the

same manner; but they were loaded less heavily, and, with decreased load, they broke only after an increased number of repetitions, as indicated by the four other circles of Curve A. In addition to these, two other tests were made at still lower stresses but the specimens did not break. These two tests are indicated by the two solid black circles of Curve A. The first one was evidently not given enough repetitions for one to expect failure, but the last one withstood 48,200,000 repetitions and lies to the right of the straight line drawn approximately through the first five points.

Now, the Curve A is represented by the equation

$$S = 217{,}000\, R^{-0.12},$$

which has the form

$$S = CR^n,$$

in which S is the maximum stress used in each test and R is the number of repetitions of this stress required for rupture. The coefficient, 217,000, was found by extending the line A to the left until it intersected the vertical line $R = 1$ (i. e., 10°) and the stress at this intersection was read off the logarithmic scale as 217,000 lbs. per sq. in. The coefficient is the stress given by the curve for a single repetition. All the coefficients given in Table I in the column marked C were found in the same way. The value of the exponent, -0.12, was found by measuring the angle (130°) which this line makes with the horizontal axis and then taking one tenth of its natural tangent. The factor "one-tenth" comes in because, in Fig. 1, the scale used along the vertical axis in plotting the stresses is ten times the scale used along the horizontal axis in plotting the repetitions. In the same way the exponent for each curve of Fig. 1 has been found and is listed in the table under the column marked n.

In looking over the curves of Fig. 1 it is evident that in many cases the straight line represents the results of endurance tests very accurately throughout a considerable range of stress. One is also impressed with the approximate parallelism of many of these lines. Taking Curves B, C, D, E, F, G, M, N, and S, their average slope, represented by their exponents, is -0.091, and their average deviation from this slope is less than 15 per cent. They represent tests made in much the same way—by rotating a specimen under

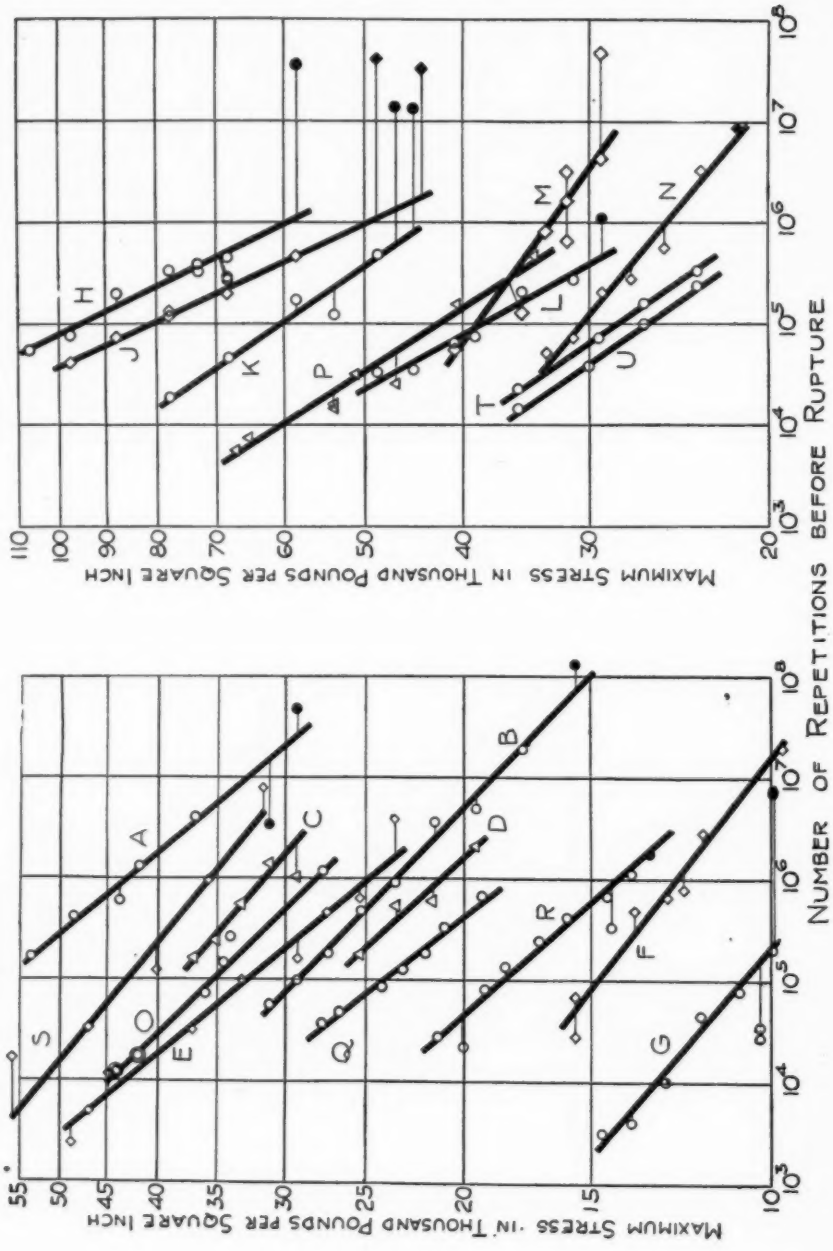

Maximum Stress in Thousand Pounds per Square Inch
Number of Repetitions before Rupture
H
J
K
P
M
L
T
N
U
S
A
O
E
C
Q
D
B
R
F
G

TABLE I.

Curve Letter.	Experimenter.	Kind of Test.	Material.	Coefficient (thousands). C.	Exponent. n.
A	Wöhler	*a*	Wrought-iron Axles, Phœnix Co.	217	−0.12
B	"	*b*	" " " " "	109	−0.10
C*	"	*b*	Cast Steel, Borsig	103	−0.09
D*	"	*b*	" " "	94	−0.11
E	"	*b*	Homogeneous Iron, P. C. & Co.	130	−0.12
F	"	*b*	Bar Copper, Heckmann	36	−0.08
G	"	*b*	Cast Iron, Locomotive Cylinder	29	−0.09
H	"	*a*	Krupp's Spring Steel, hardened	1000	−0.20
J	"	*a*	" " " unhardened	920	−0.21
K†	"	*c*	Krupp's Axle Steel	320	−0.15
L†	"	*c*	" " "	310	−0.18
M	"	*b*	" " "	90	−0.07
N	"	*b*	Cast-Steel, Vickers & Sons	97	−0.08
O	Benjamin Baker	*d*	Bars from Forth Bridge	115	−0.10
P	" "	*b*	Hard Steel	250	−0.15
Q‡	Reynolds & Smith	*e*	Annealed Cast Steel	102	−0.13
R‡	" "	*e*	" Mild "	66	−0.11
S§	F. Rogers	*b*	Unannealed Steel	110	−0.08
T	Föppl	*b*	Steel A, grooved	150	−0.15
U	"	*b*	" B, "	135	−0.14

KINDS OF TESTS.

a—Bending in one direction only (+ and 0).
b—Rotating under bending load (+ and −).
c—Tension only (+ and 0).
d—Bending back and forth (+ and −).
e—Tension and smaller compression (+ and −).

bending load. The curve for hard steel, tested by Baker‖ in much the same way, has a steeper slope; the same is also true of the grooved specimens tested by Föppl.¶ Curves H, J, K, and L are approximately parallel and represent tests in one direction only; i. e., the stresses are not reversed. They have about double the slope of the other curves mentioned. Why Curve A, on wrought iron, does not fall into this class is not clear.

The slope of any line is evidently a function of the character of the test and may be a function of some property of the material—e. g., its hardness. Many experiments are needed along this line. If it should turn out that these slopes, or exponents, are practically constant for each form of test, this would make endurance testing very simple.

*C has round shoulders near grip; D has square shoulders.

†K has round shoulders near grip; L has square shoulders.

‡Ordinates are "Half Range of Stress" instead of maximum stress.

§Carbon, 0.32 per cent.; Yield Point, 39,000 lbs. per sq. in. Most points show the mean of more than one test.

‖ *Trans. Am. Society of Mech. Engrs.*, 1887.

¶ *Mitteilungen aus dem Mech. Engrs*, Vol. 130, 1909.

As an illustration let us assume that $n = -0.10$ for grooved specimens rotated under bending load, and suppose a specimen breaks at 10,000 revolutions at a stress of 50,000 lbs. per sq. in. One may now pick out this point on his logarithmic coordinate diagram and through it draw a line at 45° sloping down toward the right. This line passes through the following points:

40,000	lbs. per sq. in.	100,000	repetitions.
31,500	" "	1,000,000	"
25,000	" "	10,000,000	"

It may be further noted that extreme accuracy is not required in the value of n. In this illustration a change of n from -0.10 to -0.09 or to -0.11 changes the value 25,000 to 26,800 or to 23,200 respectively.

Résumé.—When the results of endurance tests are plotted to logarithmic coordinates,—stress for ordinates and number of repetitions for abscissas,—the points fall upon straight lines throughout a large range of stress. These lines seem to be practically parallel for tests of a similar nature and it is proposed to use these lines by extrapolation in estimating a breaking stress for any large number of repetitions.

THE STRUCTURAL MATERIALS TESTING LABORATORIES, UNITED STATES GEOLOGICAL SURVEY: PROGRESS DURING THE YEAR ENDING JUNE 30, 1910.

By Richard L. Humphrey.

Investigations by the United States Geological Survey have been in progress for the past five years, authorized by appropriations by Congress, for the purpose of determining the nature and extent of the structural materials belonging to and for the use of the United States. The data resulting from investigations already made and in progress were expected to furnish information leading to a more efficient and economical use of such materials in the construction of public works under the direction of the Government. The annual expenditures for such work at the present time aggregate over sixty millions of dollars and the value of the saving thus effected and the increased durability of this work cannot be overestimated.

Many of these investigations, such as the fire-resistive properties of the various materials and of systems of fireproofing, a proper knowledge of the strength and other properties of the materials resulting in an increased economy in their use, have a direct bearing upon the conservation of the natural resources, which is generally admitted to be a matter of vital importance to the future prosperity of the United States. The data obtained from the first mentioned investigations have already thrown a great deal of light upon the behavior of various building materials, not only as to their fire-resistive properties under normal conditions, but also their behavior under the extreme test of a great conflagration, which has undoubtedly resulted in an improvement in the methods of fireproofing.

This information appears in reports published in Bulletins No. 324 and No. 370 of the United States Geological Survey, the former covering the reports of the San Francisco earthquake and fire and the latter giving the preliminary results of comparative

tests of the fire-resistive properties of various materials made in the Underwriters' Laboratories in Chicago, Ill.; these tests forming a part of the extensive program which has been planned.

As stated in the report of the conduct of these investigations for the fiscal year ending June 30, 1909, presented at the last annual meeting of the Society, these investigations were originally inaugurated in St. Louis, Mo., where, through the courtesy of the City and of the Louisiana Purchase Exposition authorities, some of the World's Fair Buildings were adapted for temporary quarters, which were maintained as such for a period of about five years, and were vacated when restoration of Forest Park reached the condition where further occupancy of these buildings was impossible. The equipment was then removed to the Arsenal Grounds at Fortieth and Butler streets, Pittsburg, Pa., where they were reinstalled in buildings which were placed at the disposal of the Department of Interior through the courtesy of the Secretary of War. As the work developed, it was found necessary to establish a laboratory at Northampton, Pa., for the Isthmian Canal Commission for the inspection of the cement used in the construction of the Panama Canal, these tests being placed under the direction of the United States Geological Survey. Under an arrangement with the Secretary of the Treasury, the laboratory maintained in the office of the Supervising Architect for the testing of materials delivered for use in construction of the various Federal buildings, was transferred and placed under the direction of the United States Geological Survey. A laboratory was also established at Atlantic City, N. J., where investigations of the effect of sea water on various structural materials are being conducted.

Owing to the equipment and efficiency of these laboratories, there has been a constantly increasing demand by the various government bureaus for investigations and tests of various kinds; and the transfer of the work from some of these bureaus, as in the case of the Supervising Architect, to the jurisdiction of the United States Geological Survey, was for the purpose of so concentrating the work as to avoid duplication in several departments of the Government.

Work has steadily developed each year and the number of tests have increased, as may be seen in the accompanying tables. From the inspection of these tables it will be noted that more than

one hundred and seventy thousand tests and determinations have been made during the period of operation, and at a cost of less than two dollars per test, which, when consideration is given to the large test pieces which have been made and tested, such as beams, columns, and floor slabs, is a price which compares very favorably with commercial conditions.

TABLE I.—A SUMMARY OF PHYSICAL AND CHEMICAL TESTS,* MADE AT THE STRUCTURAL MATERIALS TESTING LABORATORIES OF THE UNITED STATES GEOLOGICAL SURVEY AT ST. LOUIS, MO., ATLANTIC CITY, N. J., AND PITTSBURG, PA., SEPTEMBER 15, 1904, TO JUNE 30, 1910.

Nature of Tests.	Kind of Tests.	Sept. 15,'04 to June 30,'08	July 1,'08 to June 30,'09	July 1,'09 to June 30,'10	Sept. 15,'04 to June 30,'10
Physical.	Test pieces made...	40,798	8,280	14,581	63,659
	Test pieces tested..	45,397	7,831	15,798	69,026
	Auxiliary	4,337	2,712	8,154	15,203
Total.....		90,532	18,823	38,533	147,888
Chemical.	Analyses	1,909	681	1,743	4,333
	Determinations	11,812	5,795	8,189	25,796
Total.....		11,812	5,795	8,189	25,796
Grand total		102,344	24,618	46,722	173,684

In the tests of cement for the Isthmian Canal Commission, the lowest commercial bid for this work was one cent per barrel. Through the operation of the laboratory installed and operated by the United States Geological Survey, these tests are being made at a cost of considerably less than one-half of a cent per barrel, which shows that the work is being done as economically as would be possible under commercial conditions.

This report covers the operation of the work accomplished for the fiscal year; and for reasons which will appear later, a summary has been given covering the entire period of the work. During the fiscal year ending June 30, 1910, a large variety of

*Exclusive of the work done in the Laboratories in Washington, D. C., and Northampton, Pa.

work has been accomplished, although the beginning of the year was devoted chiefly to the completion of the transfer of the laboratories in Forest Park to the buildings in the Arsenal Grounds in Pittsburg.

By far the larger portion of the work had to do with the testing of structural materials intended for the use of the various government bureaus, and under the wording by the appropriation for the year, these materials must belong to and be for the use of the Government. Most of this work was done in the laboratories in Pittsburg, among which may be noted tests of 108 samples of Manila rope, 203 samples of wire rope, involving tests on 439 individual wires and sundry other special tests required in connection with the purchasing department for the Isthmian Canal Commission; a special series of tests of 449 samples of cement for the Supervising Architect; the inspection and testing of 22,800 barrels of cement for the Navy Department, and sundry special tests of steam and water hose, waterproofing compounds, full-size glass lights, twist drills, fire and clay brick and other materials. In nearly every case these tests were accompanied with an urgent request for prompt reports.

During the year there were, exclusive of the tests made in the Washington and Northampton Laboratories, a total of 38,533 physical tests made as compared with 18,823 made last year, and 8,189 chemical analyses and determinations as against 5,795 last year, of which about 83 per cent. were tests and investigations made on behalf of various government bureaus. The remaining tests cover the investigations of properties of cement, mortars, plain and reinforced concrete, clays, clay products and other structural materials. For convenience of reference, the same order will be used in discussing the work in detail as that used in presenting the report for the previous fiscal year.

INVESTIGATION OF CLAY PRODUCTS.

The investigation of clay and clay products, which was inaugurated during the last fiscal year, has been continued with a somewhat limited appropriation, which has restricted their full scope. However, much work of a preliminary character has been accomplished during the year, covering the following studies and investigations:

TABLE II.—A SUMMARY OF THE CHARACTER AND NUMBER OF PHYSICAL TESTS MADE ON BEHALF OF THE VARIOUS GOVERNMENT BUREAUS, DURING THE FISCAL YEAR ENDING JUNE 30, 1910, IN THE PITTSBURG STRUCTURAL MATERIALS TESTING LABORATORIES.

Bureau.	Character of Material.	July 1 to Dec. 31, 1909.	Jan. 1 to June 30, 1910.	Total.
Isthmian Canal Commission.	Cement and mortar	42	...	42
	Concrete	18	125	143
	Permeability	6	3	9
	Auxiliary	30	175	205
	Manila rope	100	8	108
	Wire rope	54	149	203
	Individual wires	...	489	489
	Rubber hose	1	1	2
	Steel rods	...	3	3
	Twist drill	...	3	3
	Total	251	956	1,207
Supervising Architect.	Cement and mortar	6	5,377	5,383
	Permeability	18	....	18
	Damp proofing	18	....	18
	Auxiliary	24	84	108
	Glass lights	4	....	4
	Brick	369	115	484
	Total	439	5,576	6,015
Navy Department.	Cement and mortar	...	3,012	3,012
	Permeability	...	54	54
	Damp proofing	...	54	54
	Concrete	...	30	30
	Slate	2	....	2
	Auxiliary	4	2,618	2,622
	Total	6	5,768	5,774
Reclamation Service.	Cement and mortar	...	18	18
	Concrete	14	14	28
	Total	14	32	46
Quarter-master's Department.	Cement and mortar	96	48	144
	Auxiliary	110	80	190
	Slate	12	28	40
	Concrete	...	6	6
	Total	218	162	380
Total		928	12,494	13,422
Test piece made		289	9,283	9,572
Grand totals		1,217	21,777	22,994

1. The study of the effect of preheating upon the drying of clays has been completed and the manuscript has been submitted for publication. It has been found in this work that the preheating of crude clays before manufacturing them into wares solved in practically all cases the difficulty met in drying the excessively plastic surface clays of the middle West and the West. The cause of this improvement in drying was found to be due to the coagulation of the colloidal matter and of the extremely fine particles of the clays.

2. The study of the control of colloids has been completed and is now being prepared for publication. The effect of certain soluble salts upon the plasticity of clays has been studied. Certain fundamental laws operating towards increasing or decreasing the plasticity have been formulated. Treatment of clays as regards the casting process has been clearly defined and it has been shown that the amount of sodium silicate necessary to produce a workable casting mixture is fixed and any excess or deficiency in the amount of this reagent is injurious.

3. Owing to the fact that the so-called melting point of fire bricks is no criterion whatever as to their suitability in practical use, a study has been made of the gradual softening which fire bricks undergo.

While fire bricks show a higher crushing strength at temperatures of 1050° or 1100° C. than they do in the cold condition, this is not true at temperatures above 1200° C. At heats each this point, inferior fire bricks soften perceptibly, even under low loads, while high grade products show no change. Based upon this reasoning a definite test has been worked out in which each fire brick is subjected to a temperature of 1350° C., under a load of 50 lbs. per sq. in., the duration of the test being five hours. An acceptable grade of fire brick will not show a deformation nor compression of more than 1 in. to the standard length of 9 ins. The bricks are placed in a furnace edgewise and a load thus impressed upon the test piece.

4. The investigation dealing with the toughness of clays and shales, particularly the latter, has been continued, but is far from completion, owing to the various factors entering into the production of the so-called toughness. A large amount of work is necessary to bring out the effects of fineness of grain, water

content, method of shaping, drying, rate of heating and rate of cooling.

5. One hundred and ninety-two crushing tests have been made of building brick, available for use in the city of Washington, D. C. Plants which are in position to compete for this work have been visited and a report has been made to the Supervising Architect as regards the brick industries within a radius of one hundred and fifty miles.

6. Three hundred and ten crushing tests of bricks have been made on edge and flatwise. It was proven that the edge test is more comparable than the flat test, and hence is better suited to form a basis of comparison as regards the quality of the bricks.

7. Additional work is in progress in which the growth of strength of clay products is studied with reference to the burning temperature. In this investigation the true porosity, taking into account the enclosed pore space into which water cannot penetrate, is correlated with the crushing strength. Curves have been completed, based on crushing strength and observation tests in which the compressive strength on edge is correlated with the wider observation for 48 hours.

The practical value of the results so far obtained is indicated by a demand for the results of these investigations and the results of investigations which have been planned.

INVESTIGATION OF LIME.

This work, as indicated in the report for last year, is supplemental to the work of the clay products investigations, preliminary announcement of its inauguration having been made in the previous year's report. The amount of money available for this work has been very small and little more has been possible than to form the nucleus of the organization which will be necessary to carry on this important work, for it should be noted that while lime is one of the oldest of building materials, very little is really known of its properties and it affords a very fruitful field for investigation. The work accomplished during the year may be summarized as follows:

1. A Bulletin on the Studies of the Lime Industry of the United States has been completed and submitted for publication.

2. An extensive research as regards the composition, burning temperature, the hydration, and the properties of lime composition is in progress. The object of this work is to clear up some points in connection with the burning and slacking of lime, which at present have not been explained. By reason of a lack of investigative work in this field, it has been found necessary to work out the method of investigation which has also covered the designing of special apparatus.

3. The study of plasticity by means of various methods, in correlation with viscosity and other properties of the plastic material, is being continued.

INVESTIGATION OF BUILDING STONE.

The work outlined in the previous year, covering extensive investigation of the building stones of this country, which has been inaugurated involving a systematic survey covering not only the geological and economical features, but also the various physical properties such as strength, durability, and resistance to fire, weather and other destructive agencies, has been continued only to a limited degree through lack of funds. This work is of the highest importance and it is to be hoped that Congress will provide the requisite money so that a knowledge of the properties of the natural building stones of the country may be completely set forth in a government bulletin. Similar bulletins are to be found in European countries, the value of which cannot be overestimated, especially as regards the Federal buildings, in which the natural building stones are used almost exclusively for ornamental purposes; the durability of which as regards weathering and resistance to fire are of the highest importance in this monumental type of building, which generally must serve for a great many years.

WASHINGTON LABORATORY.

This laboratory is maintained almost exclusively for the purpose of making tests of material, delivered under government specification, for the purpose of determining whether they meet the standard of the quality prescribed. The work accomplished during the year showed more than 50 per cent. increase over that of the previous years; this increase is due to the increased

demands of the various government bureaus for its service and is a strong argument in favor of the necessity for such a laboratory.

FIRE-RESISTIVE TESTS.

Lack of funds has prevented the inauguration of any new work, and the work accomplished has consisted in the continuance of the study of the rate of heat conductivity of concrete and in collating the results of the investigations of previous years. During the year, the first series of tests of fire-resisting properties of building materials appeared in Bulletin No. 370, previously referred to. The enormous annual fire losses in this country, which are so very much greater than those of any foreign country, should be a sufficient argument for the need of such investigations. These investigations can be very properly undertaken by the government since it does not insure its buildings, and for this reason it behooves it to erect the most fire-resistive type of building possible, a building so designed that it will offer a maximum resistance to fire both within and without; and for the practical reason previously referred to,—namely, to conserve the natural resources of the country as regards building materials by providing information which will lead to a more economical and more intelligent use of such materials in buildings so designed as to offer a maximum resistance to fire, thereby tending to conserve these natural resources by reduction of the enormous annual losses through fire.

CHEMICAL LABORATORY.

In addition to the routine work consisting of the analyses and tests of the structural materials for the various government bureaus, there have been carried on investigations of the effect of alkali on cement, mortars, and concretes at the request of the Reclamation Service; a chemical study of the action of sea water on various structural materials in conjunction with the Atlantic City Laboratory; an investigation of the materials for waterproofing of cement, mortars, and concrete; and there has also been started an investigation of the value of bitumens for waterproofing as well as for roofing purposes, which has been undertaken at the request of the Supervising Architect.

These investigations of the effect of alkali on various structural

materials have been both chemical and physical. The former is the result of the reaction of the salts with the material and the latter is the physical result of freezing or crystallization of the salts in the material. These tests have been carried on in connection with the investigation of the effect of sea water in conjunction with the Atlantic City Laboratory, as it is quite evident that the effect of sea water is similar to the effects of the alkaline salts. It may be stated in a preliminary way that it is quite evident that good concrete work is less liable to disintegration from either sea water or alkalies; whether poor concrete work can be rendered immune against such action either by the addition of foreign materials, or a change in the composition of the cement, or the method of using it, is yet to be determined. It is a fact, however, that very dense, strong concrete is little affected by such action. It is also evident that only certain salts have been so far shown to affect concrete, namely, the so-called "black alkali" encountered in the arid districts of Wyoming, Montana and the Dakotas.

The investigation of waterproofing compounds involving a study of some seventy compounds has been completed.

The investigation on bitumens has not been carried on sufficiently to give definite results other than that both lake asphalt and asphalt oil residues when subjected to the continued action of water decompose rapidly, while coal tar preparations of good quality, under similar conditions, appear to be fairly resistive. The investigations carried on involve the study of the action of water on bitumens when placed upon discs of cement, the discs being completely covered with water; also when placed upon discs of cement in which the disc is so immersed that the water attacks the bitumens through the capillary pores in the disc and also in a similar manner when the water contains 2 per cent. of sodium sulphate. The above series has also been repeated using a disc of clay and using also a 2-per cent. solution of sodium carbonate. The action of oxygen on bitumens has also been studied; all these investigations have involved a chemical analysis of the materials under investigation as received and after the action of the water and salts upon them.

The Government being one of the largest consumers of cement used in its irrigation work in the arid regions and also for docks, government fortifications and other structures along the sea coast,

it is evident that it is highly essential that a definite knowledge be had of the manner in which concrete should be prepared and placed in order to render the structure immune from action of either alkalies or sea water, since economical conditions demand that concrete shall be largely used in such structures. Therefore, the continuance of these investigations with a view of arriving at definite conclusions in the matter is of the highest importance.

SPECIAL TESTS FOR GOVERNMENT BUREAUS.

At the request of many of the government bureaus, special tests of materials have been undertaken,—that is, tests of the properties of the materials not ordinarily covered by specific methods and thus involving the designing of special apparatus and methods for making such tests. In Table II will be found a summary indicating the character of some of these tests. Each year finds an increasing demand for such work and the amount of work that can be done is limited by the funds available. However, under the decision of the Comptroller of the Treasury Department, it has been found possible to secure a credit for work carried on in this manner, and the extent of the work possible has thus been greatly increased. The great value of work of this kind in enabling government officials to pass judgment on the merits of the various materials submitted for use in government structures, is inestimable, and indeed, it is hardly possible to efficiently carry on the work of the Government without such investigative tests. It would seem to be the part of wisdom to appropriate liberally for this work, since the cost would be more than compensated for by the economy effected through the use of the cheapest and most suitable materials for the purpose.

THE ISTHMIAN CANAL COMMISSION.

This work has consisted of a continued study of sands and gravels selected in the vicinity of the site of the canal, in order to determine their adaptability for use in concrete for the various structures connected with the canal. A great many tests have also been made of wire and Manila rope cables, involving a study of the physical properties of the rope and of the chemical qualities of the preservative and a determination of the character of the

center used in wire ropes, besides a great number of special tests in connection with the purchase of supplies for this work. The inspection of the cement to be used in the construction of the canal is treated separately under the Northampton Laboratory.

UNITED STATES RECLAMATION SERVICE.

The investigation of the effect of alkaline salts on concrete construction has been continued and tests have been made of various cements and waterproofing compounds; also tests of cubes of the concrete made on the site on which work was in progress.

SUPERVISING ARCHITECT AND TREASURY DEPARTMENT.

The work for this department, in addition to the analyses made in the Washington Laboratory, has consisted of the investigations of the value of asphalts and coal tar products for both roofing and waterproofing purposes. It has also included an investigation of the physical properties of building stone, gravel, sand and brick from various sources in which are contemplated the erection of Federal buildings, this latter covering the investigation of more than one hundred samples of various classes of materials.

QUARTERMASTER'S DEPARTMENT.

Investigations have been made not only of cement but also as to the value of various sands and building stones and other special materials submitted for use in the various constructions under the control of this department.

NAVY DEPARTMENT.

Investigations have been conducted of a number of materials submitted for waterproofing purposes. There has also been inaugurated an inspection of the cement intended to be used in work under the control of the Bureau of Yards and Docks.

CONCRETE AND REINFORCED CONCRETE.

The survey of the constituent materials of concrete which was inaugurated several years ago had been continued in a limited way and there is yet a great deal of work to be done. There has been

completed and transmitted to Washington for publication, a study of the results of the tests of 364 reinforced concrete beams, 13 ft. long and 8 by 11 ins. in section, together with a like number of cylinders and cubes and a smaller number of bond test pieces. This study covers the influence of the percentage of reinforcement and of the character of aggregates, proportions, and age of concrete upon the strength of the beams.

A series of tests have been undertaken on different classes of concretes, and of various proportions, for the purpose of determining the bond, shear, tensile and compressive strength, together with the weight per cubic foot. The first report on the various materials on the market for waterproofing and damp-proofing cement mortars and concrete has been prepared for publication. Investigations have also been made of various suggested improvements in the methods for testing cements.

The following investigations of concrete have been undertaken and the tests are either wholly or partly completed ready for collation and publication:

1. The completion of the study and investigation of the strength of plain concrete beams, embodying results of the tests of beams 52 weeks old and the corresponding tests of short beams, cubes and cylinders. The preliminary results of these investigations are contained in the United States Geological Survey Bulletin No. 344.

2. A study of 96 reinforced concrete beams, together with the corresponding cubes and cylinders, in which have been used plain bars $\frac{1}{4}$ in., $\frac{3}{4}$ in., 1 in. and $1\frac{3}{4}$ ins. in diameter, tested at ages of 4, 13, 26 and 52 weeks.

3. A study of the results of tests of 108 beams reinforced with bars $\frac{1}{2}$ in. in diameter in which the variables were the aggregates (cinder, granite, limestone and gravel) and the age (2, 7 and 14 days).

4. A study of the results of tests of 108 beams, together with the corresponding cubes and cylinders of the concrete used in the making of the beams, in which limestone has been used in proportions of 1:4:8, 1:3:6 and 1:$1\frac{1}{2}$:3. Bars 1 in. in diameter were used for reinforcement, and the beams were tested at the ages of 4 and 13 weeks.

5. A study of results of tests of 216 beams, together with the

corresponding cubes and cylinders of the concrete used in the making of the beams. The beams were tested for spans of 6, 8, 10 and 12 ft. at the ages of 4 and 13 weeks, bars 1 in. in diameter being used for reinforcement.

6. (*a*) A study of results of tests of beams, together with the corresponding cubes and cylinders of the concrete used in making the beams, consisting of three sets of 9 beams each, in which the reinforcement is exposed at the center for a distance of 14 ins., permitting the direct determination of the deformation in the steel.

(*b*) Beams in which oiled tin pieces have been placed every four inches in the lower portion of the beam in order to destroy all tension in the concrete.

(*c*) A study of the tests of beams 13 ft. in length, together with the corresponding cubes and cylinders of the concrete used in the making of the beams, in which the reinforcement has been exposed for a distance of 9 ft. and is provided with anchorages at the end of the beam.

7. A study of the effect of the personal equation in molding in the laboratory and under practical conditions, consisting of 90 beams, together with the corresponding cubes and cylinders of the concrete used in the making of the beams, made by laborers taken from work in progress in St. Louis by three construction companies and the employees of the testing laboratory, gravel and limestone being used as aggregates in the proportions of 1: 3: 6. The beams were reinforced with bars 1 in. in diameter and tested at the ages of 4 and 13 weeks. Wooden and metal molds were used; the beams were aged under ordinary atmospheric conditions, and in the damp closet of the laboratory.

8. An auxiliary series of 48 beams, together with the cubes and cylinders of the concrete used in the making of the beams, made under the same conditions as indicated in 7. The beams were reinforced with stirrups and the ends of the reinforcement were bent upwards, the object being to insure a failure by compression. The aggregate was gravel, in the proportions of 1: 2: 4.

9. A study of the results of tests of 15 beams, with the corresponding cubes and cylinders made from the concrete used in making the beams. The beams were reinforced with bars 1 in. in diameter. The aggregate was gravel, the proportions 1: 2: 4, and the

age 4 weeks. The loads were applied at the center, third and quarter points, and at four and eight points.

10. The second series of tests of the fire-resistive properties of various materials made in the Underwriters' Laboratories at Chicago.

11. The results of tests of the constituent materials of concrete, giving results of tests similar to those given for sands and gravels used as aggregates of mortars, published in United States Geological Survey Bulletin No. 331.

12. The results of tests of 2,000 cement hollow building blocks.

13. The results of tests for bond, shear, tensile and compressive strength of concrete.

14. The results of preliminary tests of reinforced concrete slabs 12 ft. square supported on two and four edges, reinforced with plain bars ½ in. in diameter and various forms of metal fabric. Tests were made at the age of 4 weeks; the proportions were 1:2:4, using gravel as the aggregate.

15. Additional results of tests of constituent materials of mortars, being a continuation of the results reported in United States Geological Survey Bulletin No. 331.

16. The results of tests of the permeability of cement mortars and concretes of various compositions and a study of the effect of the use of various waterproofing materials.

17. The results of investigations of the effect of alkalies and sea water on various structural materials.

18. The results of tests of mortar columns and of plain and reinforced concrete columns 12 ins. in diameter and lengths varying from 10 to 30 ft. Sand was used as an aggregate for the mortar in proportions of 1:1, 1:2, and 1:4, and gravel as aggregate for the concrete in proportions of 1:1½:3, 1:2:4, and 1:3:6, tested at ages of 4 and 13 weeks. The reinforced concrete columns cover the study of the effect of various percentages of reinforcement of various kinds.

The test pieces for this latter investigation have been only partly made and tested.

The amount of money that has been set aside for these investigations has never been very large. There seems to be a prevalent idea that $100,000 has been available each year for the investigations of concrete and reinforced concrete. As a matter of fact,

during the first year of his work, a large amount of money was spent for equipment and at no time in the last three years has the amount of money actually available for this purpose exceeded $15,000, while the amount expended this year for the investigation of concrete has not exceeded $5,000. For this money, a large amount of investigative work has been accomplished, although, of course, this would appear to be very small when contrasted with the supposed available appropriation of $100,000. The investigation of these materials by the Government is of the highest importance, since it will lead to a better knowledge of their properties, thus giving confidence to the government engineers in the use of the material with a consequent decrease in the cost of government buildings. While this information is primarily of value to the government engineers, it is also of value to all constructing engineers, and no better work could be undertaken by the Government than the continuance of these investigations on an extensive scale, which will lead to the acquirement of definite knowledge of their properties and thereby tend to increase their use and result in more economical structures. Only the Government can undertake work of this kind, since the character of the tests involve of necessity ample funds and facilities which are not possessed by individuals or corporations and which are possessed by scientific institutions to only a limited degree. Aside from this, the value of such tests would be greatly enhanced when made by the Government.

ATLANTIC CITY LABORATORY.

Work in this laboratory, covering the effect of sea water on the various structural materials, has involved the making of 3,761 test pieces and the testing of 1,683. In addition to this, there have been analyzed 196 samples of sea water in which 30 different cements were exposed, for the purpose of determining the alteration of the cement through a study of any change in the composition of the sea water. Only a very small amount of money was available for carrying on these investigations under the engineer in charge with one laborer as assistant. The investigations thus carried on consisted of: first, laboratory or scientific investigations of the chemical and physical changes which take place in cements exposed to sea water; second, the determination of the cause of

failure of structures in sea water and the practical conditions under which structures can be successfully erected in sea water; and third, investigations of the suitability of special materials and forms of construction for sea-water work.

The early work was of a preliminary character, carried only sufficiently far to indicate the manner in which the problem should be attacked. The work has not progressed far enough to justify any conclusions as yet, although a preliminary bulletin is in progress indicating the results obtained up to the present time, without expressing any conclusions as regards the results. One of the interesting experiments has been a study of the methods of placing concrete in sea water, and it has been found that concrete placed in a dry mold or form, even where the sea water is permitted to cover the concrete immediately after placing, develops over 300 per cent. greater compressive strength than a portion of the same batch of concrete placed through a pipe in molds submerged in sea water. It has also been found that concrete placed in a mold free from sea water and exposed to sea water immediately after placing, develops a strength equal to that obtained from test pieces which have been hardened 26 weeks before exposure to sea water. It is apparent as a result of the investigations, that concrete, when properly made,—that is, properly proportioned so as to secure a maximum density and allowed to harden before being subjected to the action of sea water,—can be used in sea water without danger of injury. The work, however, is only just started and final conclusions must be withheld until more definite results are obtainable.

NORTHAMPTON LABORATORY.

This laboratory, as in previous years, engaged in routine tests of cement for use in the construction of the Panama Canal, on behalf of the Isthmian Canal Commission. Up to the end of the last fiscal year some 121,000 barrels of cement had been inspected, involving the test of 1,267 samples. For the fiscal year ending June 30, 1910, 1,155,333 barrels of cement had been inspected, (Table III) involving the tests of 11,909 samples or an increase of nearly ten fold. The inspection to date has covered the shipment of nearly one quarter of the cement which will be used in the

TABLE III.—WORK ACCOMPLISHED AT THE NORTHAMPTON TESTING LABORATORY OF THE STRUCTURAL MATERIALS TESTING LABORATORIES OF THE UNITED STATES GEOLOGICAL SURVEY DURING THE FISCAL YEAR ENDING JUNE 30, 1910.

Kind of Work.	Total for Year.
Bins sampled	285
Number of samples taken	11,909
Briquettes made	98,952
Briquettes tested	89,615
Pats made and tested	46,198
Time of set	11,417
Specific gravity	10,758
Fineness	10,587
Number of barrels shipped	926,405
Barrels of cement tested	1,155,333
Test pieces made	145,150
Test pieces tested	135,813
Auxiliary tests	32,762
Total tests	313,725

construction of the Panama Canal; this cement has met all the requirements of the work and the inspection has met with the hearty approval of the Isthmian Canal Commission, as being in every respect satisfactory.

CONCLUSION.

In the five years in which the investigations of structural materials have been in progress under the direction of the United States Geological Survey (in what has been designated during the past three years as the Technologic Branch), a very large amount of valuable data has been accumulated relating to concrete and reinforced concrete. The collation and study of this data has been very seriously handicapped through the lack of funds and the larger portion of the appropriations was devoted to such work as was urgently required by the various government bureaus, which made it impossible to set aside any large amount of money for the work of collating data already obtained.

After the results of investigations have been completed, there has been a delay of as much as two years in securing the publication, due to the naturally slow process and a lack of funds. It should be borne in mind that under the present governmental

methods the charge for printing reports does not come against the appropriation for the work but must come out of a special appropriation covering all government printing. This appropriation is divided by the Public Printer among the various departments of the Government and each departmental head, in turn, allots a certain amount to each bureau. The printing of the various reports must, therefore, be passed upon by the head of the bureau under which the work is done.

In the case of the Structural Materials Division the amount of money available was wholly inadequate for the purpose and the result is that some of the bulletins have been held up for several years by reason of lack of funds for printing.

It is regrettable that such a condition of affairs exists, since it seriously delays the work of publication of the results of the investigations. These results should be collated and published as rapidly as possible after their completion, for as time passes it becomes more difficult to complete the work since the details are no longer fresh in the minds of those who supervised the work.

It would seem that since this work was authorized by Congress and the tests have been made and in many cases the material completed for publication, steps should be taken to provide funds to secure their immediate publication, otherwise, the time and money that has been expended in the making of these tests will be wasted. Moreover, an early publication of these data is desirable, since there is an urgent need for such information and delay in its publication will in a measure destroy its greatest value.

Inasmuch as the last Congress did not continue the appropriation for these investigations they necessarily came to an end at the close of the present fiscal year. Congress did, however, appropriate $50,000 to the Bureau of Standards for the continuation of the investigations of structural materials belonging to and for the use of the Government. This amount, however, was insufficient to perform the routine tests required by the various government bureaus and as a consequence little experimental work has been possible, and the work has consisted principally of routine tests and analyses. By reason of the fact that the equipment and personnel was under the charge of the Secretary of the Interior and the appropriation was made to the Department of Commerce and Labor, an arrangement was made by which the equipment

and personnel in the Interior Department was placed at the disposal of the Department of Commerce and Labor for the ensuing fiscal year.

It is to be hoped that ample funds will be provided for the prosecution to completion of the important investigations now under way. Whatever may be the ultimate outcome, it is certain that funds should be immediately provided for the publication of the tests which have already been made so that the information may thereby be rendered available. This work should be properly completed under the direction of those who directed the investigations.

The value of governmental investigations of this character becomes apparent to any one who familiarizes himself with the work which is being done in foreign countries, and its importance is clearly illustrated in the two magnificent laboratories maintained by the German Government, namely, Physikalisch-Technische Reichsanstalt at Charlottenburg and the Material-Prüfungsamt der Königlich Technischen Hochschule at Gross-Lichterfelde-West bei Berlin.

The former laboratory is engaged in the work of standardization requiring precise measurements and extremely accurate determinations, while the latter laboratory performs work of the more practical nature dealing with problems having commercial application in which accurate work is essential, although not requiring the precision required for the work of standardization. The former work requires the services of the trained physicist and the latter the services of the engineer and chemist. The Bureau of Standards is modeled after the Physikalisch-Technische Reichsanstalt and the work being performed by the United States Geological Survey is similar to that of the Material-Prüfungsamt der Königlich Technischen Hochschule.

By reason of the distinct differences of the character of the work of these two laboratories they should be distinct in their operation just as is the case of the German laboratories above referred to.

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PAST OFFICERS.

The Society, from its organization in 1898 till its incorporation under its present name in 1902, was designated the American Section of the International Association for Testing Materials. The officers and members of the Executive Committee during this four-year period were as follows·

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